SCHOOL OF
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INDIANA
DEPARTMENT OF HIGHWAYS

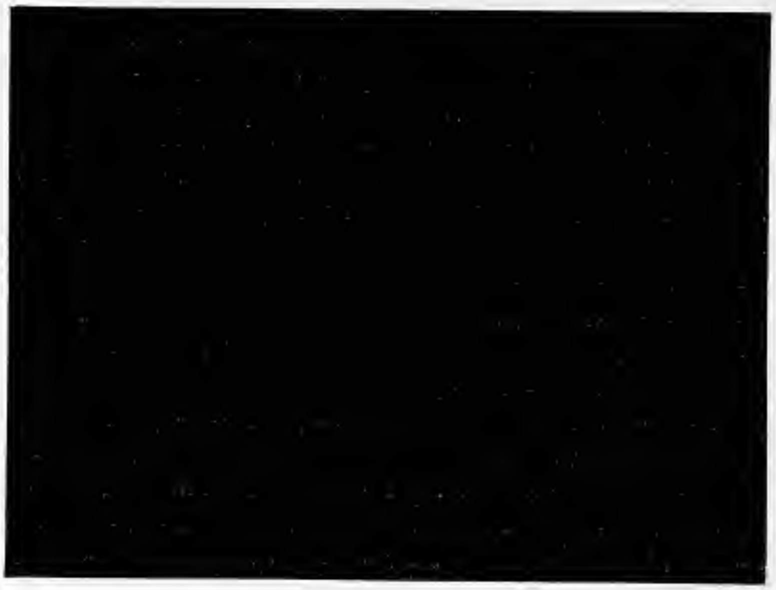
JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-93/1
Final Report

STATISTICAL ANALYSIS OF OVERLOAD VEHICLE EFFECTS ON INDIANA HIGHWAY BRIDGES

Prasad NBR
Donald W. White
Julio A. Ramirez
Thomas Kuczek

PURDUE UNIVERSITY



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Final Report

GUIDELINES FOR PERMITTED OVERLOADS
PART II
STATISTICAL ANALYSIS OF OVERLOAD VEHICLE EFFECTS ON INDIANA HIGHWAY BRIDGES

Donald W. White
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Purdue University

Joint Highway Research Project

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Purdue University
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16. Abstract

This report summarizes an analytical investigation carried out to develop a set of guidelines for regulation of overload vehicles in Indiana. A formula based first phase evaluation of overload permit requests is developed through statistical study of the rating of a representative sample of the highway bridges in Indiana using a representative sample of overload vehicles observed in the state in 1990 and 1991 plus the HS 20 design vehicle and the two Indiana Toll Road loadings. A sample of 148 bridges is chosen from a total population of 3700 Indiana highway bridges using a proportionate stratified random sampling process. A sample of 25 trucks, with the truck parameters uniformly distributed over their ranges is compiled from the 1990 and 1991 truck population (permit vehicles obtained from INDOT and the AASHTO HS Design Vehicle). The selected trucks are used to rate bridges in the selected sample using the Bridge Analysis and Rating System (BARS) program at the operating stress level. BARS is based on elastic line girder and truss analysis. The allowable load, W, is subjected to linear regression analysis with several bridge and truck parameters as regressor or independent variables.

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STATISTICAL ANALYSIS OF OVERLOAD VEHICLE EFFECTS ON INDIANA HIGHWAY BRIDGES

IMPLEMENTATION REPORT

This report summarizes the analytical investigation carried out to develop a set of guidelines for regulation of overload vehicles in Indiana. A formula-based first phase evaluation of overload permit requests is developed through statistical study of the rating of a representative sample of the highway bridges in Indiana using a representative sample of overload vehicles. A sample of 148 bridges is chosen from a total population of 3700 Indiana highway bridges using proportionate stratified random sampling process. A sample of 25 trucks, with the truck parameters uniformly distributed over their ranges is compiled from the 1990 and 1991 truck population (permit vehicles obtained from INDOT) plus the AASHTO HS20 Design vehicle and the two Indiana Toll Road loadings. The selected trucks are used to rate the bridges in the sample using the bridge Analysis and Rating System (BARS) program at operating stress level. BARS is based on elastic line girder and truss analysis. The allowable load, W, is subjected to linear regression analysis with several bridge and truck parameters as regressor or independent variables.

The wheel base, and the product of HS truck capacity and the wheel base are found to be the best route independent and route dependent regressor variables respectively. The HS truck capacity of a bridge is defined as the maximum gross vehicle weight that the bridge can carry within operating stress levels for a vehicle having the same configuration in terms of axles and axle weight distribution as the standard HS20 truck with variable axle spacing. The quality-of-fit is considerably lower for the data with wheel base greater than 120 feet and no significant model is found for this range of wheel base. Hence, the final results are limited to vehicles with wheel base less than 120 feet and greater than 10 feet. Also, the truck must have a minimum of 6 equivalent axles if the wheel base is more than 105 feet, 4 if the wheel base is greater than 70 feet, or a minimum of 3 equivalent axles if the wheel base is more than 25 feet. The number of equivalent axles for any given vehicle is obtained by counting closely spaced axles as a single equivalent axle. Any group of axles that are placed within a length of 9 feet is considered as one equivalent axle. If the permit truck has wheel base outside the range of 10 to 120 feet or has less than the minimum required equivalent axles for its wheel base, then that permit must be sent for detailed analysis of all the bridges in the route of the permit vehicle. These restrictions also apply on the truck configurations recommended for a given gross weight. The square root transformation is applied on the allowable load to achieve a homogeneous variance and also to satisfy the normality assumption of the underlying data in regression analysis. Formulae are developed at 85%, 90%, 95% and 99% confidence levels for both route dependent and route independent models. A practical procedure is formulated for implementation of the results of this study.

1. FORMULA DEVELOPMENT AND RESPONSE ANALYSIS

In this study the wheel base, L, and the product of the HS truck capacity of bridge and wheel base are statistically identified, based on single and multiple linear regression analyses of the data from rating analyses, as the key variables for predicting the allowable load, W, in route

independent and route dependent permit evaluation procedures respectively. The HS truck capacity of a bridge is defined in this study as the allowable load at operating stress level for that bridge using an HS20 design truck with variable spacing as specified in the AASHTO Specifications (1989).

1.1 Route Independent Model

A route independent model by definition, must contain variables dependent only on truck characteristics. The variance of the allowable load, W, is found to be not homogeneous for the entire range of wheel base. The variance actually increases with the level of allowable load. Hence the data is transformed using a square root transformation:

$$\sqrt{W} = C_1 L + C_2 \tag{1}$$

Using this model in the regression analysis, the coefficients, C_1 and C_2, and the standard deviations in the individual predictions are determined. The confidence limits are also determined and the results are shown in Table 1.

1.2 Route Dependent Model

In general, the allowable load at the operating stress level depends both on the bridge and truck characteristics. Using a model that involves both truck and bridge parameters, more accurate predictions can be made compared with a model using only truck parameters. The bridge parameter referred to as HS truck capacity is introduced to develop a route dependent model. Again the data is transformed using square root transformation.

$$\sqrt{W} = C_1 \ (HS\ truck\ capacity) L + C_2 \tag{2}$$

This model is used in the regression analysis. The coefficients C_1, C_2 and the standard deviations are obtained for the individual predictions as well as the confidence limits. The results are shown in Table 2.

2. APPLICATION OF ROUTE INDEPENDENT AND ROUTE DEPENDENT FORMULAE

The findings of this study showed that the route independent and route dependent models overestimate the allowable loads for a small fraction of cases, depending on the confidence level used. It is explained later how that is only as expected. However, for the cases involving the weakest bridges, as denoted by very low HS truck capacity values, the over estimation ratio,

$$OER(\%) = \frac{Predicted\ Truck\ Load\ -\ Actual\ Allowable\ Truck\ Load}{Actual\ Allowable\ Truck\ Load} x100 \tag{3}$$

OER (%), given in Eq. (3) is beyond acceptable limits, except for the route dependent model at 99% confidence level. The issue of overestimation is discussed in detail in Chapter 4 of the report.

Therefore, it would seem as if only the route dependent model could be used without excessive overstressing of some of the weakest bridges in the state. The maximum overestimation ratios by the route independent model are 67%, 95%, 111% and 122% at confidence levels 99%, 95%, 90% and 85% respectively. It has been identified in this study that the bridges belonging to groups Continuous Prestressed Concrete Box Beams (CPCBB), Continuous Reinforced Concrete Slab (CRCS) and Steel Thru' Truss (STT) are the ones highly overestimated by the route independent formulae. It is also observed that these overestimated bridges exhibit low HS truck capacity values when rated using the BARS program.

It should be noted that the confidence limits by definition lead to some cases of overestimation. For example, at 99% confidence level, it is expected that in 1% of the cases the predicted load will overestimate the bridge allowable load. The entire sample of bridges in this study was analyzed at operating stress level (36% overstress beyond the design stress or inventory level) which is clearly different from the ultimate capacity level. Hence overestimation does not necessarily mean failure of the bridge. For example, the maximum stress in structural steel at the operating stress level is only $0.75F_y$. Therefore, in cases where the strength is governed by yielding, there is approximately 33% more capacity available in structural steel bridges beyond the stress level used for structural analysis in this study. There is also an unknown amount of reserve capacity in the bridges that is not utilized due to the analysis limitations of the BARS program. In the CRCS and CPCBB bridges the critical section was found to be the negative moment region over the continuous support. However, this is in part due to the fact that the BARS program does not consider the negative moment redistribution for continuous spans of prestressed and reinforced concrete bridges. Furthermore, truss bridges are very efficient in carrying loads. In the STT bridges, the third group found to be highly overstressed by the proposed route independent formulae, the stringers and not the main trusses themselves were found to be the critical elements.

3. HS TRUCK CAPACITY OF BRIDGE AS AN INDICATOR OF WEAK AND STRONG BRIDGES

Table 3 shows the distribution of data points in the entire sample overestimated by the route independent model, with respect to the HS truck allowable load (capacity) of bridges. The first column "HS truck capacity" contains different classes of HS truck capacity. The second column "Percentage Frequency" shows the distribution of bridge sample into various HS truck capacity classes. The rest of the columns under "Percentage Confidence Level" show the percentage data points of the particular class of HS truck capacity that are overestimated by the proposed formulae at the respective confidence levels. The average HS truck capacity of bridges in the sample is HS36.7 (66 tons).

For HS truck capacity less than HS22.2 (40 tons), these bridges are overestimated for all the 17 vehicles with wheel base less than 120 feet for confidence levels 85%, 90% and 95%, and overestimated for 50% of the vehicles at 99% confidence level. It can be concluded that the proposed route independent model overestimates almost all bridges with HS truck capacity less than HS22.2 (40 tons) for most of the trucks with wheel base less than 120 feet. Only 1.6% than percent of bridges in the sample have HS truck capacity less than HS22.2 (40 tons).

None of the bridges with HS truck capacity more than HS30.6 (55 tons) are overestimated at 99% confidence level. Nearly 85% of the bridges in the sample have HS truck capacity more than HS30.6 (55 tons). None of the bridges with HS truck capacity greater than HS38.9 (70 tons) in the sample are overestimated even at 85% confidence level. Approximately 37% of the bridges in the sample have HS truck capacity greater than HS 38.9 (70 tons).

From these observations, it can be concluded that HS truck capacity of a bridge is a good indicator of whether that bridge will be overestimated for trucks with wheel base less than 120 feet and greater than 10 feet. Furthermore, the 99% confidence level route independent formula can be used for bridges with HS truck capacity more than 40 tons and the route independent formulae at confidence levels 85%, 90% and 95% can be used for bridges with HS truck allowable load greater than 45 tons, without exceeding tolerable limits of overestimation of the allowable load.

4. FORMULA IMPLEMENTATION

4.1 Route Independent Model

The route independent model can be used either for judging whether a particular overload permit request can be granted without performing detailed analysis, or for specifying a minimum wheel base and a minimum number of equivalent axles required for a given gross weight to be transported, (so as to grant the permit for the overload vehicle without performing detailed analysis.) In either case, the user must chose one of the confidence levels from the choices of 85%, 90% and 95%, and 99%.

4.1.1 Case 1: Evaluation of a Given Overload Permit Request

To evaluate a given overload permit, the wheel base of the overload vehicle should be substituted in the route independent model and allowable vehicle weight calculated at the chosen confidence level. If the allowable vehicle weight is more than the requested gross load of the permit vehicle, the permit may be granted. Otherwise the permit request should be forwarded to the next phase for detailed analysis of the bridges in the route.

4.1.2 Case 2: Minimum Wheel Base for a Given Gross Weight

The given gross weight of the overload truck should be substituted as the predicted allowable load in the route independent model at a chosen confidence level and the required wheel base is then computed. The wheel base of the permit truck must be greater than the calculated value to transfer the given overload. If the minimum wheel base required is less than 10 feet, 10 feet should be used as minimum wheel base. If it is more than 120 feet, then no recommendation can be made about the wheel base of the truck. Any truck longer than 120 feet must be analyzed for all bridges in the route. If the minimum wheel base required is within 10 feet and 120 feet, any truck, which satisfies the minimum equivalent axle requirement and has wheel base between minimum required and 120 ft., can be granted permission to transport the given gross weight without detailed analysis. The appropriate minimum number of equivalent axles is specified based on the wheel base: - 6 if the wheel base is greater than 105 feet, - 4 if more than 70 feet, - 3 if more than 25 feet.

4.2 Route Dependent Model

To use this model, the user must know the route of the permit vehicle and the HS truck capacity of all bridges in the route. Again, this model can be used either for judging whether a particular overload permit request can be granted without performing detailed analysis or for specifying the minimum wheel base and a minimum number of equivalent axles required for a given gross weight so as to grant the permit without detailed analysis. The user must select a confidence level from the choices of 85%, 90%, 95% and 99%.

4.2.1 Case 1: Evaluation of a Given Overload Permit Request

To evaluate a given overload permit, the lowest HS truck capacity of the bridges in the route and the wheel base should be substituted in the route dependent model and calculate the predicted allowable load at the chosen confidence level. The permit can be granted if the predicted allowable load is greater than the gross weight of the overload vehicle, otherwise the overload vehicle must be sent to next phase for detailed analysis.

4.2.2 Case 2: Minimum Wheel Base for a Given Gross Weight

To determine the minimum wheel base, the minimum HS truck capacity of the bridges in the route and the gross weight are used in the route dependent model for the desired confidence level and the required minimum wheel base is computed. If this is in between 10 feet and 120 feet, then any wheel base between the minimum wheel base and 120 would be permissible for the truck to grant the permit without detailed analysis. Otherwise, the given gross load with different trucks can be judged only after detailed analysis. The appropriate minimum number of equivalent axles is specified as in Sec. 4.1.2.

5. FUTURE WORK

An efficient use of the results of this study can be made through a procedure for evaluation of overload permits that is route dependent to a certain extent. Initially, INDOT should identify all the highway bridges in the state with HS truck capacity less than 45 tons and 40 tons respectively. The route independent formula at 85%, 90%, or 95% confidence level or the route dependent formula at 99% confidence level can be used, if all the bridges in the route of the permit vehicle have HS truck capacity more than 45 tons. If the least HS truck capacity of the bridges in the route of the permit truck is greater than 40 tons and less than 45 tons, then either the route independent or route dependent formula at 99% confidence level can be employed. If any of the bridges in the route have HS truck capacity less than 40 tons, then the route dependent formula at 99% confidence level should be used.

Currently, INDOT does not have the HS truck capacities for all the highway bridges in Indiana. As can be seen from the above description of the proposed permit evaluation procedure, the HS truck capacity of bridges is essential. INDOT has identified a set of bridges that give low allowable loads for various trucks during BARS analysis. It is recommended that the HS truck capacity be found for all the bridges in the state and then a list of bridges in the state and then with low HS truck capacity values be developed. However, until that time at least the currently identified weak bridges should be analyzed for HS truck and their HS truck capacity used in the evaluation of permit trucks.

Additional work is needed to predict the allowable loads for trucks with wheel base greater than 120 feet. It must be noted that the average length of the bridge in the sample considered is about 138 feet. It is possible that for a wheel base exceeding 130 ft., a considerable part of the truck will be outside the bridge when placed in a critical position. This could make the wheel base a less relevant parameter in this instance. It would seem, that to handle such a situation, bridge parameters such as length should be included in the formulae.

Finally, it is recommended that the HS truck capacity, defined as the maximum vehicle weight for the HS truck configuration at the operating stress level, be determined for STT (Steel Thru' Truss) bridges in the state of Indiana. In these bridges the critical component was found not to be the main longitudinal load carrying trusses, but the longitudinal stringers. It is further suggested that a sample of these bridges be instrumented and subjected to control loadings to monitor the actual stresses in the critical elements. This would help to further refine the assumptions in regard to the load distribution used in the rating of this type of bridge. This refinement would be extremely useful to correctly assess the performance of Steel Thru' Truss bridges subjected to overload vehicles. In this study these bridges were shown to be one of the most critical groups in terms of overestimation of load carrying capacity.

Table 1 Summary of Route Independent Model

$\sqrt{W} = c_1 L + c_2$ for trucks with $10 \le L \le 120$ft.

c_1 (coeff.)	0.0484 ($ton^{1/2}$/ft.)
c_2 (intercept)	6.891 ($ton^{1/2}$)
σ_{in} for individual prediction	1.031 ($ton^{1/2}$)
r, coefficient of Correlation	0.830
$W^{1/2}$ ($ton^{1/2}$) at 50%	0.0484L + 6.891
$W^{1/2}$ ($ton^{1/2}$) at 85%	0.0484 L + 5.822
$W^{1/2}$ ($ton^{1/2}$) at 90%	0.0484L + 5.570
$W^{1/2}$ ($ton^{1/2}$) at 95%	0.0484 L + 5.195
$W^{1/2}$ ($ton^{1/2}$) at 99%	0.0484L + 4.493
W (ton) at 50%	$2.34 \times 10^{-3} L^2 + 0.667L + 47.48$
W (ton) at 85%	$2.34 \times 10^{-3} L^2 + 0.564L + 33.90$
W (ton) at 90%	$2.34 \times 10^{-3} L^2 + 0.539L + 31.02$
W (ton) at 95%	$2.34 \times 10^{-3} L^2 + 0.503L + 26.99$
W (ton) at 99%	$2.34 \times 10^{-3} L^2 + 0.435L + 20.19$

Table 2. Summary of Route Dependent Model

$$\sqrt{W} = c_1 \; HS \; truck \; cap. \; x \; L + c_2 \; for \; truck \; with \; 10 \le L \le 120$$

c_1 (coeff.)	$7.495 \times 10^{-4} \; \frac{ton^{-\frac{1}{2}}}{ft.}$
c_2 (intercept)	6.795 ($ton^{1/2}$)
σ_{in} for individual prediction	0.686 ($ton^{1/2}$)
r, coefficient of Correlation	0.93
$W^{1/2}$($ton^{1/2}$) at 50%	7.495×10^{-4} HS truck cap. x L + 6.795
$W^{1/2}$($ton^{1/2}$) at 85%	7.495×10^{-4} HS truck cap. x L + 6.084
$W^{1/2}$($ton^{1/2}$) at 90%	7.495×10^{-4} HS truck cap. x L + 5.916
$W^{1/2}$($ton^{1/2}$) at 95%	7.495×10^{-4} HS truck cap. x L + 5.667
$W^{1/2}$($ton^{1/2}$) at 99%	7.495×10^{-4} HS truck cap. x L + 5.200

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Table 3. Percentage distribution of data points, overestimated by the route independent model, for different ranges of HS truck capacity at 85%, 90%, 95%, and 99% confidence levels

		Percentage Confidence Level			
HS truck cap.	Percentage Frequency	85%	90%	95%	99%
25-30	0.7	100.0	100.0	100.0	94.0
30-35	0.7	100.0	100.0	100.0	76.5
35-40	0.2	100.0	100.0	100.0	50.0
40-45	2.1	90.6	79.3	50.9	13.2
45-50	3.4	48.2	30.6	11.8	1.2
50-55	8.1	39.2	20.6	7.8	0.5
55-60	11.7	14.2	6.8	1.4	0.0
60-65	20.7	5.8	1.5	0.6	0.0
65-70	16.1	6.4	3.2	0.5	0.0
70-75	14.8	0.0	0.0	0.0	0.0
75-80	10.9	0.0	0.0	0.0	0.0
80-85	2.7	0.0	0.0	0.0	0.0
85-90	3.4	0.0	0.0	0.0	0.0
90-95	2.7	0.0	0.0	0.0	0.0
95-100	1.3	0.0	0.0	0.0	0.0
100-105	0.0	0.0	0.0	0.0	0.0
105-110	0.7	0.0	0.0	0.0	0.0

Table 1 Summary of Route Independent Model

$$\sqrt{W} = c_1 L + c_2 \text{ for trucks with } 10 \le L \le 120\text{ft.}$$

c_1 (coeff.)	0.0484 ($ton^{1/2}$/ft.)
c_2 (intercept)	6.891 ($ton^{1/2}$)
σ_m for individual prediction	1.031 ($ton^{1/2}$)
r, coefficient of Correlation	0.830
$W^{1/2}$ ($ton^{1/2}$) at 50%	0.0484L + 6.891
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$W^{1/2}$ ($ton^{1/2}$) at 99%	0.0484L + 4.493
W (ton) at 50%	$2.34\text{x}10^{-3}L^2 + 0.667L + 47.48$
W (ton) at 85%	$2.34\text{x}10^{-3}L^2 + 0.564L + 33.90$
W (ton) at 90%	$2.34\text{x}10^{-3}L^2 + 0.539L + 31.02$
W (ton) at 95%	$2.34\text{x}10^{-3}L^2 + 0.503L + 26.99$
W (ton) at 99%	$2.34\text{x}10^{-3}L^2 + 0.435L + 20.19$

Table 2. Summary of Route Dependent Model

$$\sqrt{W} = c_1 \text{ } HS \text{ } truck \text{ } cap. \text{ } x \text{ } L + c_2 \text{ } for \text{ } truck \text{ } with \text{ } 10 \le L \le 120$$

c_1 (coeff.)	$7.495\text{x}10^{-4} \dfrac{ton^{-\frac{1}{2}}}{ft.}$
c_2 (intercept)	6.795 ($ton^{1/2}$)
σ_m for individual prediction	0.686 ($ton^{1/2}$)
r, coefficient of Correlation	0.93
$W^{1/2}$($ton^{1/2}$) at 50%	$7.495\text{x}10^{-4}$ HS truck cap. x L + 6.795
$W^{1/2}$($ton^{1/2}$) at 85%	$7.495\text{x}10^{-4}$ HS truck cap. x L + 6.084
$W^{1/2}$($ton^{1/2}$) at 90%	$7.495\text{x}10^{-4}$ HS truck cap. x L + 5.916
$W^{1/2}$($ton^{1/2}$) at 95%	$7.495\text{x}10^{-4}$ HS truck cap. x L + 5.667
$W^{1/2}$($ton^{1/2}$) at 99%	$7.495\text{x}10^{-4}$ HS truck cap. x L + 5.200

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ABSTRACT

Special attention must be given to the overload vehicle effects on highway bridges so as not to seriously undermine the life span of the bridges. In this study the effects of overload vehicles on bridges in Indiana is studied through regression analysis. Based on the results of the analytical studies, a set of guidelines is formulated for regulation of overload vehicles. A representative sample of 148 highway bridges in Indiana is selected from the bridge population using a proportionate stratified random sampling process. The stratification is based on the bridge material type, construction type and structural form. A sample of 25 overload vehicles with characteristics uniformly spread over the respective ranges is used in the rating, using the Bridge Analysis and Rating System (BARS), of the selected sample of bridges. The results of the BARS analysis are subjected to statistical simple and multiple linear regression analysis in order to identify the significant truck and bridge parameters influencing the allowable load. The wheel base, the distance between the first and last axle of the truck, is found to be the best parameter to predict the allowable load using a route independent model involving only truck parameters. Furthermore, The product of the wheel base and the allowable load of the bridge for an HS truck at operating stress level is found to be the best route dependent parameter.

Data transformations are used on both the models to satisfy the assumptions of regression analysis. Simple formulae for permitting of overload vehicles are obtained at confidence levels 85%, 90%, 95%, and 99% for both models. The performance of each of the individual strata of bridges is compared and the weak groups are identified. The bridge and truck combinations that are overestimated by the formulae are studied closely. A route dependent procedure is recommended based on the findings of the analytical and statistical studies so as to limit the degree of overestimation of the allowable load for the weak bridges within acceptable levels.

CHAPTER 1

INTRODUCTION

1.1 Overload vehicles in Indiana

The demand to transport heavier loads using highways is ever increasing. The state of Indiana is no exception to this trend. Special attention must be given to these vehicles since they can undermine the life-span of the various components of the highway system. The state of Indiana regulates the truck loads in terms of various legal limits [1] on truck attributes.

Trucks carrying more than the legally permitted load fall into the category of overload vehicles. An overload permit from the Indiana Department of Transportation (INDOT) is required to drive such a vehicle on the highways and highway bridges of the state. Trucks that do not fall within the legal dimensions also must obtain a permit from INDOT. The work reported in this report is a study of the effect of overload vehicles on the bridges of Indiana. It is estimated that the permit division at INDOT currently (1992) receives 4200 overload permit requests each year with gross weight more than 108,000 pounds. These are called super loads. The current trends indicate an increasing number of these types of requests in the near future.

1.2 Current procedure

Presently, overload vehicle permits with gross weight from 80,000 pounds to 108,000 pounds are evaluated in terms of limits [1] on the load per single, tandem and tri-axles. The overload permits with gross weight more than 108,000 pounds are processed in two phases. In phase I, a simply supported beam and a two equal-span continuous beam are analyzed for the given permit vehicle for spans from 20 feet to 120 feet in increments of 10 feet. The equivalent HS loading of the given permit vehicle is calculated by comparing the bending moments induced by the permit vehicle with those induced by the HS20 design vehicle [2]. The performance of the permit vehicle is assumed satisfactory, if its equivalent HS loading is less than HS30, i.e., 1.5 times the HS20 design truck. If the permit vehicle is not found satisfactory in phase I, it is sent to a phase II evaluation requiring for a detailed load rating, which involves the truck, route and structure specific information. Prior results from phase I, in terms of the acceptable truck drawings, are also used for a quick evaluation of overload permits in phase I, when the requested permit truck matches with the prior acceptable permits.

In the phase I of the current procedure only beam type structures are considered. Hence, other types of bridges such as trusses or arches are not directly addressed. The girder cross-sectional properties are assumed uniform along the length and multi-span bridges are represented with only 2-span bridges. It is observed that long permit vehicles with multiple axles are controlled by the negative moment at the central support of the two equal-span continuous beam. From past experience, INDOT has found the allowable loads for these long trucks to be too conservative based on this procedure.

Nevertheless, the approximate nature of the procedure demands that the limits on its use be very restrictive.

It is important to have a more rational procedure in phase I, so as to avoid the risk of granting unsafe permits in phase I, while reducing the number of cases which need to be handled in phase II.

1.3 Formula based procedure

An efficient methodology for the evaluation of overload vehicles in phase I should involve a safe, general, simple, and either route independent or route dependent evaluation of the vehicle configuration. This phase I evaluation can be achieved by means of a simple and conservative formula dependent either exclusively on truck parameters for route independent evaluation or on simple bridge and truck parameters for route dependent evaluation. Such a formula could be based on structural mechanics and statistical regression analyses. Such a formula will allow a quick response to many of the routine types of overload requests. If the vehicle does not pass the phase I, a next phase consisting of a more detailed rating of the bridges in the route is necessary.

1.4 Background

Quick and safe methods for evaluating the effects of loads on the highway system have been sought for many years. Over the past years, research has resulted in the U.S. House document that contains the so-called "Formula B":

$$W = 500 \left[\frac{L\ N}{N-1} + 12\,N + 36 \right] \tag{1.1}$$

where W is the gross vehicle weight in pounds not to be exceeded, N is the number of axles in the vehicle or load group, and L is the out-to-out distance between extreme axles in feet. Formula B addresses load limits of vehicles in regular operation across the U.S. Aspects such as fatigue, pavement deterioration as well as stress limitations are addressed by the formula and axle weight limitations.

Recent work conducted by Pucket and Lieber [3] developed simple formulae given below at different confidence levels for the evaluation of overload vehicles for bridges in the highway system in the state of Wyoming using operating stress levels. These statistically derived formulae are linear equations based on the wheel base, defined as distance between first and last axles, and the gross weight. They are:

$$95\% \text{ passing } W = 0.543\, L + 29.35 \tag{1.2a}$$

$$99\% \text{ passing } W = 0.399\, L + 26.02 \tag{1.2b}$$

Where gross weight, W, is given in tons and wheel base, L, in feet. The formulae, although route independent, are based upon the sampling of Wyoming's HS20 infrastructure bridges rated for representative truck configurations. The use of the formulae is therefore limited to major highway routes.

Noel & James [4] have also developed formulae given below for route independent evaluation of permits using 5% and 30% overstress beyond the design stress level for HS20 and H15 designed bridges respectively. These formulae are also based on wheel base. They are :

$$W = 0.50\,L + 17 \text{ for } 8 \text{ ft.} \leq L \leq 56 \text{ ft.} \tag{1.3a}$$

$$W = 0.25\,L + 17 \text{ for } L \geq 56 \text{ ft.} \tag{1.3b}$$

Where gross weight, W, is in tons and wheel base, L, in feet. In the work reported herein, bridges are analyzed at operating stress level (as in the studies by Pucket and Lieber), which is at 36% overstress beyond the design stress level.

1.5 Objectives

The main objective of this study is to develop a simple method for evaluating overload permit requests in the state of Indiana. This method should preferably serve as a quick, safe and route independent first-level evaluation for a given overload vehicle configuration. The appropriate constraints for the use of this method will be determined. In addition, it must be user-friendly for non-technical personnel.

A secondary objective is to provide guidelines for selection of overload trucks which will satisfy permit requirements. A tertiary objective is to identify the important bridge parameters, study their influence on the allowable load and propose a simplified route dependent formulae using them.

1.6 Scope and approach

To determine formulae for the allowable load of permit vehicles, the first task is to identify the important truck and bridge parameters that influence the allowable load. For this purpose, a sample of Indiana highway bridges is rated using a sample of overload vehicles and the results are evaluated using least squares based regression analysis.

After identification of the important truck & bridge parameters, route independent and route dependent models is formulated. The route independent approach must contain only truck parameters. The route dependent must contain in addition to truck parameters, only simple bridge parameters, which can be extracted easily from the bridge database for all the bridges in the route. The confidence limits for allowable load using both models at 85%, 90%, 95%, and 99% confidence levels is calculated assuming normal distribution of the residuals.

The route dependent model should predict the allowable load more accurately than the route independent model as it depends on both bridge and truck parameters. Either the route dependent or route independent model can be used in phase I for quick evaluation of overload permits. The route dependent model requires some data for the bridges in the route, thus it will require additional work compared to the route independent model. However, the extra work should result in improved accuracy of prediction of allowable load.

1.7 Report outline

Proportionate stratified random sampling is used to select a representative group of bridges to be used in the development of route dependent and route independent methods for overload permit evaluation by INDOT personnel. A vehicle sample is chosen from the permit requests collected by INDOT over the past two years (1990 and 1991) so as to cover uniformly the entire range of variations of truck parameters such as number of axles, wheel base and other truck parameters. These sampling methods are described in Chapter 2 along with the statistical procedure to be used in identifying the

significant truck and bridge parameters, and in calculating the confidence limits. Conceptual figures of sample overload trucks are also included in this chapter.

Several linear regression models are studied in Chapter 3 using truck and bridge parameters as regressor or independent variables and the allowable load as the dependent variable. The coefficient of correlation is evaluated and presented in a tabular format for all the regression models. The data is graphed for some of the more significant variables. The regression models are also studied for individual bridge groups. The best parameters for prediction of the allowable load in route independent and route dependent schemes are identified in this chapter.

In Chapter 4, data transformations are applied to achieve a homogeneous variance of the residuals. The confidence limits for allowable load using the best route independent and route dependent models are calculated at confidence levels 85%, 90%, 95%, and 99%. The performance of individual groups of bridges is compared with these confidence limits. For bridge and truck combinations where the proposed confidence limits overestimate the allowable load, the degree of unconservatism is studied quantitatively and summarized. The proposed confidence limits are also compared with previous studies of similar nature.

Chapter 5 includes the summary of this research study, the procedure for implementation of the results of this study as well as the scope for future work. The necessary tables, figures, references, and the appendix are included after chapter 5 in that order. The appendix contains detailed description of the truck and bridge variables considered in this study.

CHAPTER 2

METHODOLOGY AND SAMPLING PROCESS

2.1 Sample selection procedure

The importance of the procedure for sample selection can not be over-emphasized in any statistical study. A good representative sample is essential to arrive at valid conclusions at the end of any statistical study. If the elements are chosen randomly from the population, the sample is called a simple random sample. If the population is subdivided into different groups and then each group is sampled randomly, it is called stratified random sample. Furthermore, if the number of elements selected from each group is in proportion to the size of that group, then it is called a proportionate stratified random sample. When the sub-division of population is done so as to form distinct groups, the proportionate stratified random sampling would lead to a more accurate representative sample of the population.

2.2 Sampling of bridges

Preliminary information was obtained from INDOT for about 3700 Indiana highway bridges. These bridges are classified into 19 different groups based on their structural form, material type, and form of construction. The groups are shown in Table 2.1. Both beam and girder, as used in this table in defining the steel bridge groups, are parallel to the traffic, but the former is a cold-formed unit, while the later is an assembled unit.

Within each group, the bridges are further divided into subgroups based on the number of spans and the overall length of the bridge. Using a proportionate stratified random sampling procedure, a sample of 148 bridges is obtained. The distribution of the full bridge population and of the bridge sample is shown in Table 2.2.

2.3 Sampling of overload vehicles

Based on 550 permit requests received by INDOT during 1990 and 1991, 80 representative loading patterns were identified. Various truck parameters have been identified: the number of axles, N, the distance between the front and the last axles, L (referred to in this work as wheel base), number of equivalent axles, N_{eq} (defined below in the next section), the distance of the resultant load from the first axle, $\bar{x}$, and the standard deviation of the vehicle load distribution, x_{σ}. The distribution of these parameters is plotted for the 80 trucks in Figs 2.1-2.6. Refer to the Appendix for the definition of above variables.

In Figs 2.1-2.6, the range of Y-axis is divided into 20 classes and the data is plotted at the mid-values of the classes. The horizontal dashed lines separate adjacent classes. Either number of axles, N, or number of equivalent axles, N_{eq}, is plotted on X-axis. The X-axis range is divided into vertical strips of unit width. So for a given Y-class and a given value for X, i.e either N or N_{eq}, a block is formed in the grid. The number of dots in each block represent the number of truck patterns that fall within that block area. These points are shown from left to right within each block. Thus, each of these figures form a two dimensional distribution of the truck patterns.

One objective of this study is to formulate a procedure for a route independent evaluation of overload permit requests. This procedure can only contain truck parameters as input variables. Lack of proper representation of truck parameters in the truck sample can lead to serious restrictions on the scope of the results. Hence, it is important to obtain a truck sample that would cover uniformly the entire range of variation of the chief truck characteristics. The Figs 2.1-2.6 show the variation of some of main truck variables. A uniform sample of 22 trucks is selected based on these plots. In addition to these trucks, the HS20 design vehicle with variable spacing [2] and the two recommended Indiana Toll Road loadings, which are to be used as alternate bridge loadings for bridge design in the future, are included in the sample. The 25 vehicles are shown in Fig. 2.7. The trucks are numbered sequentially from 101 to 125. The order and numbering of trucks is of no particular significance. The HS20 design vehicle with variable spacing is numbered 125, while the two Indiana Toll Road design vehicles are numbered 123 and 124.

2.4 Definition: Equivalent Axles

The number of equivalent axles for any given vehicle is obtained by counting closely spaced axles as single equivalent axle. An arbitrary criterion of 9 ft. length is chosen for the definition of an equivalent axle, i.e, any group of axles that are placed within a length of 9 ft. is considered as one equivalent axle. The importance of this parameter is studied in later chapters and compared with the actual number of axles.

2.5 Bridge analysis and rating

Detailed information for the 148 selected bridges was obtained from INDOT. Bridges Analysis and Rating System (BARS) [5] was used in the analysis of bridge sample for the 25 selected trucks. The procedures in this program are based on elastic line girder and truss analysis. The rating of various structural components, i.e, girders, floor beams, stringers, and truss members, is performed using working stress method at the operating stress levels defined in AASHTO manual [6] and summarized in Table 2.3. The operating stress level is 1.36 times the inventory stress level or design stress level, which correspond to day to day normal traffic. Stringers and girders lie parallel to the direction of traffic, while floor beams lie perpendicular to the traffic. Only flexural analysis is performed in this evaluation. The BARS program redistributes the negative moments over the supports by 10% to the positive moment area for compact section members belonging to the structural steel and composite steel & concrete bridges. No redistribution of negative moments is used for either prestressed concrete or reinforced concrete bridges. The wheel load distribution factors for a two lane loading and the impact factor specified by the AASHTO standard [2] are used in the bridge analysis. The distribution factors are used in distributing the wheel load to the structural components, i.e, girders, stringers, and floor beams.

2.6 Database

The bridge components considered include stringers, girders, floor beams, and trusses. The BARS program gives the maximum allowable truck load for each of these elements in the bridge for a given truck. This information is recorded for all the

elements. In this study, the most critical of these values is used in the subsequent analysis as the maximum allowable load at operating stress level for the given vehicle and the bridge.

Five different material types are also identified among the bridges. They are Structural Steel (SS), Reinforced Concrete (RC), Composite Steel and Concrete (CSC), Prestressed Concrete (PSC) and Composite Prestressed Concrete (CPS).

The various parameters based on bridge and truck characteristics and the results from BARS analysis are formed into a database. The items stored in the database are summarized in Table 2.4.

2.7 Statistical procedure

In general, allowable load may depend on a large number of detailed bridge and truck parameters. The purpose of this study is to identify the primary bridge and truck parameters that explain the variation in the dependent variable, i.e., the allowable load. Based on these parameters different confidence limits can be calculated.

A linear regression analysis is performed on various models, which relate allowable load as dependent variable to the bridge and truck parameters. It is assumed that the dependent variable is normally distributed at any given set of values for the independent variables. This assumption is verified at a later stage in the studies. The coefficient of correlation, r, used in assessing the importance of each model, is defined as follows;

$$r = \left[\frac{\text{sum of squares due to regression}}{\text{sum of squares about mean}} \right]^{\frac{1}{2}} \tag{2.1}$$

$$0 \leq r^2 \leq 1$$

The closer the r^2 value to 1, the better the model.

Once the best model is chosen, the standard deviation for an individual prediction is computed. The predicted value at any set of values for the regressor or independent variables is obtained by reducing the mean predicted value by a certain factor, β, which is dependent on the confidence level desired, multiplied by the standard deviation of the individual prediction. The factor β at different confidence levels is obtained from the assumed normal distribution.

$$\text{i.e, Predicted value} = \text{mean predicted value} - \beta\,\sigma_{in} \tag{2.2}$$

where

β (85% passing) = 1.0365

β (90% passing) = 1.2816

β (95% passing) = 1.6450

β (99% passing) = 2.3260

2.8 Summary

In this chapter, based on the study of a total population of 3700 Indiana highway bridges, a sample of 148 bridges is selected using a proportionate stratified random sampling process. A uniform sample of 25 trucks is selected from a sampling of the 1990 and 1991 truck population, (i.e., permit vehicles obtained from INDOT) and from the AASHTO design vehicle [2]. In the next chapter, various regression models are studied and the results of the statistical analysis are presented.

CHAPTER 3

STATISTICAL ANALYSIS AND RESULTS

In this chapter, the influence of the truck and bridge parameters introduced in chapter 2 on the allowable load at the operating stress level is studied. Single and multiple linear regression models are formed with bridge and truck parameters as regressor variables, and the allowable load, W, as the dependent variable. Least squares based regression analysis is performed for each model using the statistical analysis tool SAS [7]. The significance or quality-of-fit of each model is measured in terms of the coefficient of correlation, r, defined in Eq. 2.1. In Chapter 4, the standard error in the individual predictions, σ_{in}, is calculated for the best models, and confidence limits are determined at 85%, 90%, 95% and 99% levels using Eq. 2.2.

3.1 Route independent models

A route independent model, by definition, must contain variables dependent only on truck characteristics. The r values are shown in Tables 3.1 and 3.2 for various linear regression models in terms of the wheel base, L, the number of axles, N, the number of equivalent axles, N_{eq}, the distance of the resultant of the truck load from the front axle, $\bar{x}$, and the standard deviation of the truck load distribution, x_σ. The variation of allowable load with these truck parameters is shown in Figs 3.1-3.5. It is observed that the wheel base, L, is the most significant variable. Although other variables such as

number of axles are positively correlated with the dependent variable, W, no significant improvements are achieved in the quality-of-fit by using these variables in multiple regression analysis along with the wheel base. This indicates a high correlation and interdependency among these variables.

The coefficient of any variable in the regression equation indicates the sensitivity of the allowable load due to that regressor variable. High values are observed for the coefficient of N_{eq}. Since a slight modification in the truck configuration can lead to change in the value of N_{eq}, the high coefficient can cause a great fluctuation in the allowable load. As this is undesirable, the wheel base is preferred over number of equivalent axles, since a nearly equal quality-of-fit is achieved with this variable. Moreover, wheel base is a simple parameter to understand.

It is also observed from Fig. 3.1, that the variation of W is not monotonic throughout the range of wheel base. The allowable load increases with wheel base up to a wheel base of 120 feet. For a wheel base greater than 120 feet, no clear trend is observed. Also, the allowable loads for different bridges with the same vehicle vary over a wider range for trucks with wheel base greater than 120 feet. Therefore, considering the entire range of wheel base (10 to 160 ft.) resulted in a higher standard error in the individual predictions using the different models. Hence, the database is separated for trucks with wheel base greater than 120 feet and less than 120 feet. There are 17 vehicles in the sample of 25 overload vehicles that have wheel base less than 120 feet.

Next, various regression models are tried out separately for the two sets of data. The regressor variables used in the route independent linear regression models and the respective r values are shown in the Tables 3.1 and 3.2. The data for trucks with wheel base less than 120 feet is shown in Figs 3.6-3.13 and for trucks with wheel base greater than 120 feet in Figs 3.14-3.16. The wheel base is found to be the most significant variable for data with wheel base less than 120 feet. However, no significant model is found for data with wheel base greater than 120 feet. The treatment of data in two separate sets based on wheel base resulted in substantial improvement in the quality-of-fit for data with wheel base less than 120 feet. Both linear and quadratic models for the wheel base are studied. However, the r^2 value is nearly the same for both cases.

The variance of W from Fig. 3.1 is not homogeneous with respect to the wheel base, as required by the least squares based regression analysis with underlying data from a normal population. Various data transformations are discussed in the next chapter in order to satisfy this requirement. Since no significant model is identified for data with wheel base greater than 120 feet, the final results of the route independent model are restricted to trucks with wheel base less than 120 feet. For trucks with wheel base exceeding 120 feet, a detailed route dependent analysis is recommended.

3.2 Route dependent models

As mentioned earlier, the allowable load at the operating stress level depends both on the bridge and the truck characteristics. By using models that involve both truck and bridge parameters, more accurate predictions can be made compared with models using only truck parameters. A bridge parameter referred to as HS truck capacity is

introduced in this section, and a number of route dependent models based on this parameter are studied. The HS truck capacity of a bridges is defined as the allowable load at operating stress level for that bridge using an HS20 design truck with variable spacing as specified in the AASHTO design standard specifications manual [2]. It is obtained in tons by multiplying the equivalent HS rating of the bridge for HS20 design load with a factor of 1.8. A number of new variables are defined by combining the truck and bridge parameters. These variables are listed in the left most column of Tables 3.3 and 3.4. The r values for various route dependent models are also shown in these tables. The linear models including the HS truck capacity and truck parameters such as wheel base, number of axles, number of equivalent axles are found to give high r values. The allowable load is plotted against these variables in Figs 3.17-3.19. It is observed that the variance increases with the allowable load. The above models are improved when data is limited to wheel base less than 120 feet. The variance in an individual prediction of the allowable load, using the product of HS20 capacity and wheel base as regressor variable, has reduced significantly when compared with the data without any restrictions on wheel base and the r value also improved for the same model. For wheel base greater than 120 feet, the models including the HS truck capacity, number of axles and number of equivalent axles found to be significant. However, the number of axles and number of equivalent axles vary with simple modification of the truck, thereby causing sharp changes in the predicted allowable load. As this is not desirable, these two models for wheel base greater than 120 feet are of no practical use. Since no other significant route dependent model is found for the trucks with wheel

base greater than 120 feet, the final results of the route dependent model are restricted to trucks with wheel base less than 120 feet.

The average length of a bridge in the sample is found to be 136 feet. When the truck is of wheel base in the range of 120 feet or higher, it is most likely that entire wheel base of the truck is not on the bridge for quite a number of bridges in the sample, when placed in the most critical positions. This means that the wheel base is no longer a reliable variable for the truck. This may be the reason for the observed change in the trend for trucks with wheel base greater than 120 feet in both route dependent and route independent models consisting of wheel base.

The r values for route dependent models with data separated based on wheel base of 120 feet are shown in Tables 3.3 and 3.4. The allowable load is plotted for trucks with wheel base less than 120 feet in Figs 3.20-3.22 and for trucks with wheel base greater than 120 feet in Figs 3.23-3.25 for route dependent models.

No significant improvement is noticed in multiple regression models compared to the model with the product of HS truck capacity and the wheel base. This is again due to the interdependency of the variables. The linear model with product of HS truck capacity and wheel base as regressor variable is chosen for the route dependent predictions for trucks with wheel base less than 120 feet. To make use of these route dependent results, the user must know the HS truck capacity of the bridges in the route of the permit truck. The route dependent analysis is also performed using H20 capacity of bridges. However, this is not found to be a significant variable.

The possible explanation might be that, as most bridges in the bridge population are HS truck designed, the HS truck capacity indicates better the varying extents of conservative design practices for different types of bridges and to a certain extent of different designers.

3.3 Individual bridge groups data analysis

In order to check whether the general trends noted in the database are supported by the individual bridge groups, the data is separated into 19 groups formed based on structural form, material and construction type. The linear regression analysis is performed on each group with the allowable load as the dependent variable, and the truck and bridge parameters as regressor variables. The wheel base, L, is found to be the best route independent variable, while the product of HS truck capacity and the wheel base is found to be the best route dependent parameter for each group. Hence, these two models are supported not only by the entire bridge sample, but also by the individual groups of bridges. The r values are shown for the two models for different groups in Table 3.5. The data for each group is further analyzed in chapter 4.

3.4 Correlation between number of equivalent axles and the wheel base

In practice, number of axles and their arrangement within a truck for a given wheel base limit to a small number of combinations. This will be reflected in any sample of trucks selected from the trucks that are used in practice. This may be considered as a natural restriction on the sample and hence the results, as against a forced restriction due to lack of sample representing certain sections of the truck population. As described

in Section 2.3, enough care is taken to obtain a uniformly representative sample of overload trucks from the truck population, so as to avoid forcing any extra restrictions on the results of the study. However, the results are still limited by the natural restrictions of the truck population.

The results of statistical study based on a truck sample must be limited to the same restrictions imposed by the truck population on the truck sample. It is found from the study of truck population that the wheel base is highly correlated with number of equivalent axles of the truck. The number of equivalent axles and the wheel base are plotted in Fig. 3.26 for the sample trucks with wheel base less than 120 feet. Based on this figure, minimum number of equivalent axles for different ranges of wheel base are specified. They are listed in Table 3.6. These restrictions are applicable to both route dependent and route independent models.

3.5 Summary of the findings

In summary, the wheel base is the best route independent variable and the product of HS truck capacity and wheel base is the best route dependent variable, for predicting the allowable load for bridges in Indiana. These variables are significant for all of the bridge groups. It is observed that the wheel base of the truck sample is highly correlated with the number of equivalent axles. This correlation is also imposed on the results in terms of minimum number of equivalent axles for a given wheel base. It is also observed that the variance of W is not homogeneous with W. In the next chapter, the transformation of data to satisfy approximately the assumptions made in linear regres-

sion analysis will be considered and formulae for predicting the allowable load will be developed using the two models developed in this chapter for route dependent and route independent evaluations of the overload permits.

CHAPTER 4

FORMULA DEVELOPMENT AND RESPONSE ANALYSIS

In chapter 3, the wheel base, L, and the product of HS truck capacity and wheel base are statistically identified as the key variables for predicting the allowable load, W, in route independent and route dependent permit evaluation procedures respectively. This conclusion is made based on single and multiple linear regression analyses of the database. In this chapter, these parameters are studied more closely, and the 85%, 90%, 95% and 99% confidence limits are calculated.

4.1 Route independent model

As mentioned in the Section 3.1, the variance of W is not homogeneous for the entire range of wheel base. The variance is increasing with allowable load. Hence the data is transformed using a square root transformation:

$$\sqrt{W} = c_1\, L + c_2 \tag{4.1}$$

The linear model shown above is used in the regression analysis and the coefficients, and the standard deviations in individual predictions are determined. Due to the large number of data points, the standard deviation in the individual predictions, σ_{in}, is found to be nearly constant for the entire range of wheel base. The confidence limits are calculated using Eq. 2.2. The results are shown in Table 4.1. The confidence limits are

shown in Figs 4.1 and 4.2. It can be seen in Fig. 4.1 that the variance is nearly homogeneous after the transformation. The residuals are checked for normality and found satisfactory. These confidence limits are studied in the later sections of this chapter by comparing with different bridge groups and material types.

4.2 Route dependent model

The variance of W in the route dependent model is also not homogeneous as can be seen from Fig. 3.20. It is positively related to the magnitude of the dependent variable, W. Again, the data is transformed using square root transformation.

$$\sqrt{W} = c_1 \text{ (HS truck capacity) } L + c_2 \tag{4.2}$$

The model shown above is used in the regression analysis. The coefficients c_1, c_2 and the standard deviations in an individual predictions are obtained. The standard deviation in an individual prediction is found to be nearly constant due to the large number of data points. The confidence limits are calculated using Eq. 2.2. These results are shown in Table 4.2. These confidence limits are superimposed on the underlying data in Figs 4.3 and 4.4. It should be noted that both the route dependent and route independent results are limited to trucks with wheel base less than 120 feet.

4.3 Testing the confidence levels of the formulae

Formulae for predicting the allowable load at different confidence levels are derived for both route dependent and route independent evaluation of the permits. These formulae are derived based on the performance of bridges in the sample. It is important that the confidence levels of these formulae be verified based on the performance of a

test sample of bridges.

For this purpose, a test sample of 15 bridges is chosen randomly from the bridge population. These bridges are analyzed using BARS program for 10 overload trucks selected from the previous sample of 25 overload vehicles. These 10 overload vehicles span the wheel base uniformly from 10 feet to 120 feet.

4.3.1 Confidence levels of the route independent formulae

The allowable load from the BARS analysis of the test sample is plotted against wheel base in Figs 4.5 and 4.6. The confidence limits obtained using route independent model are superimposed in these figures. The performance of the test sample of bridges against the confidence limits of the original sample is summarized in Table 4.3. The percentage data points that are below the confidence limits are either better or match with the expected number for confidence levels 85%, 90%, 95%, and 99%. This confirms the confidence levels expected from the results of route independent model.

4.3.2 Confidence levels of the route dependent model

The product of HS truck capacity and wheel base is plotted against allowable load for the test sample in Figs 4.7 and 4.8. The allowable load predicted at different confidence levels by the route dependent model is superimposed on the test sample results in these figures. The performance of the test sample is compared with the predicted allowable loads and summarized in Table 4.4. The percentage data that is below the various confidence limits match very well with the expected numbers. This proves the confidence levels of the formulae based on route dependent model.

4.4 Analysis of confidence limits of route independent model

4.4.1 Comparison of different groups of bridges

The data is separated into 19 different bridge groups and is plotted along with the confidence limits obtained for route independent model in Figs 4.9-4.27. Each figure shows the distribution of allowable load against the wheel base for the bridges belonging to a particular group. The following observations are made from these figures by comparing the underlying data with the formulae derived based on the full set of bridges. The bridges belonging to groups cpcbb, crcs, stt are overestimated by the confidence limits developed based on the entire sample of bridges. The proposed confidence limits underestimate the capacity of the bridges belonging to the groups pcb, kcsg, rcg, rca, and rcs. The groups crcg, csb, csg, kcsb and pcbb match well with the confidence limits. The rest of the bridge groups cpcib, pcib, sb, sg, spt and ksb are overestimated at lower confidence levels and estimated properly at higher confidence levels. The above observations can be seen from the Table 4.5, which shows the percentage of data points for each bridge group that lie below the various confidence limits. The first column shows different bridge groups, the second column shows the percentage data or percentage of bridges in the sample that belong to each group. The remaining columns in Table 4.5 give the percentage of data points of each particular group that are below each particular confidence limit. For example, 16.2% of the data in the sample belong to crcs group and 7.6% of the crcs data is below 95% confidence limit, while the expected data below 95% confidence limit for any group is 5%, i.e, the 95% confidence limit overestimates the crcs bridges. The last row of the same table

show the percentage of points for all bridges that lie below confidence limits. These numbers agree closely with the respective confidence levels. This proves the validity of the normal distribution assumption for the underlying data after the square root transformation. Also, the different performance of the separate bridge groups justifies the stratified random sampling and the stratification used in arriving at the bridge sample.

4.4.2 Comparison of different material types of bridges

The allowable load is plotted against wheel base for each of the material types in Figs 4.28-4.31. The confidence limits obtained for the route independent model for all bridges is also shown in the same figures. The distribution of data points with respect to these confidence limits is summarized in Table 4.6. The first column of this table show different material types, the second column show the percentage data points that belong to each of these material types and the rest of the columns show the percentage data for any given material type that lie below any given confidence limit. This table indicates that the confidence limits overestimate for prestressed and structural steel bridges, while, underestimating for composite steel and concrete, and reinforced concrete bridges.

When compared among each other, different material types of bridges, except for reinforced concrete (RC) bridges, do not exhibit much difference in the mean performance. Hence, stratification based on material types alone would not be sufficient. This supports further subdivision, as used in this study, of the material types of bridges, so as to form strata of bridges with varying performance for overload vehicles.

4.4.3 Comparison of continuous and simple span bridges

Figs 4.32 and 4.33 show the data for continuous and simple span bridges respectively along with the confidence limits of the route independent model obtained using all bridges. The percentage distribution of data points with respect to the confidence levels are shown in Table 4.7. This tables contains in the first column show different types, i.e., simple span and continuous span types, the second column show the percentage of data that belong to simple span type and continuous span type and the rest of the columns give the percentage of data for each type that is below any given confidence limit. The data indicates that the simple span bridges are predicted conservatively by the confidence limits except at 99% confidence level and continuous span bridges are predicted conservatively by the confidence limits except at 99% and 50% confidence levels.

The mean performance of simple span bridges is found to be better than that of continuous bridges. This may be due to the limitation of BARS on structural analysis in terms of negative moment redistribution in continuous bridges. The BARS program does not take into account for negative moment redistribution in reinforced concrete and prestressed concrete bridges. Not utilizing this extra capacity available in the bridge rating can lead to the perception of weak behavior by the continuous bridges.

4.5 Analysis of confidence limits of route dependent model

4.5.1 Comparison of different groups of bridges

The allowable load for different bridge groups is plotted against the product of HS

truck capacity of bridges and the wheel base of trucks in Figs 4.34-4.52. The confidence limits for the route dependent model obtained using all the bridges is also superimposed in these figures. The distribution of data points in these figures with respect to confidence limits is summarized in Table 4.8. The first column of this table gives the different bridge groups, the second column shows the percentage of the data that belong to each of the groups and the rest of columns show percentage of data in any particular group that are below a given confidence limit. For example 1.3% of the data belong to stt group and 52.9% of this data lie below the 85% confidence limit, whereas the expected data below 85% confidence limit for any group is 15%, i.e., the confidence limits calculated based on full set of bridges overestimate the allowable load for stt group bridges at 85% confidence level. It is observed that the confidence limits overestimate bridges belonging to cpcbb, pcbb and stt groups. The groups crcg, kcsb, pcib, rca, rcg, and rcs are underestimated by the proposed route dependent confidence limits, while the groups cpcib, crcs, csb, kcsg, and pcb agree very well with the confidence limits. The number of bridges from the remaining groups is small due to small group sizes. Hence, no general observations can be made for these groups. The last row of Table 4.8 shows the distribution of entire data with respect to the various confidence limits. The percentage points that are below the confidence limits match very well with the confidence levels. This proves that the assumption of normally distributed underlying data is satisfied after the square root transformation of allowable load.

4.5.2 Comparison of different material types of bridges

The data is plotted in Figs 4.53-4.56 for different material types and summarized in Table 4.9. The proposed route dependent confidence limits overestimate the prestressed concrete bridges, while reinforced concrete bridges are underestimated by the formulae. However, when compared among each other, different material types of bridges do not exhibit much difference in the mean performance. Hence, stratification based on material type alone will not be sufficient. This supports further subdivision, as used in this study, of the material types of bridges.

4.5.3 Comparison of continuous and simple span bridges

The allowable load, W, is plotted in Fig 4.57 and 4.58 for continuous and simple span bridges respectively. The data distribution with respect to the confidence limits is summarized in Table 4.10. The confidence limits predict both simple and continuous bridges with nearly equal quality of fit. No significant differences in the accuracy of prediction are observed between the continuous and simple span bridges.

4.6 Analysis of overestimation by the route independent model

The bridges, for which allowable load is less than the value predicted by a given rating formula, will be overstressed beyond the operating stress level. As this could be of concern, these data points are studied closely in order to identify the reasons for their poor performance and also to quantify the overstress beyond operating stress level. It should be noted that the confidence limits by definition lead to some cases of overestimation. For example, at 99% confidence level, it is expected that 1% of the time the

predicted load will overestimate the bridges. A quantitative study of overestimation at various confidence levels is essential in deciding on the confidence level to be selected for use by INDOT. In this regard, overestimation ratio (OER) as defined below is introduced.

$$\text{OER}\ (\%) = \frac{\text{Predicted Truck Load} - \text{Actual Allowable Truck Load}}{\text{Actual Allowable Truck Load}} \times 100 \quad (4.3)$$

The actual allowable truck load is determined placing the given truck configuration on the bridge in question and performing the analysis using operating stress levels. The predicted truck load is determined using the developed formulae for the given truck configuration. The truck and bridge combinations that are overestimated by the confidence limits of the route independent model are listed in Tables 4.11-4.14 in the order of 85%, 90%, 95%, and 99% confidence levels respectively. As mentioned in Section 4.3, bridges belonging to groups cpcbb, crcs and stt are overestimated. Hence, most of the data in these tables belong to the groups cpcbb, crcs and stt. It was also observed that most of the critical points in crcs group of bridges occur due to high negative bending moment at the interior piers. For stt type bridges, it was the stringers and not the truss elements that controlled in calculating the allowable load obtained from the structural analysis using the BARS program.

The overestimation ratio, OER, for the overestimated data points at various confidence levels is summarized in Table 4.15. It shows the actual percentage of data that is below various confidence limits, percentage frequency distribution of OER and the maximum OER for the 85%, 90%, 95%, and 99% confidence limits. For example,

12.1% of data is below the 85% confidence level, while the expected is 15%, and 55% of this data that is below 85% confidence limit has OER value less than 10%. It can be seen that more than 70% of the overestimated cases have OER value less than 30% at any confidence level given. Both the number of overestimation cases and the OER values decrease with increasing confidence level.

Particularly, four bridges with national bridge inventory (NBI) numbers 019937, 029560, 021130, and 026520 are severely overestimated by the proposed formulae for predicting the allowable load in a route independent evaluation. The first bridge belong to the bridge group crcs, the next one to stt group and the last two to cpcbb group. With the exception of these bridges the maximum overestimation ratios are only 13%, 17%, 26%, and 65% at the confidence levels 99%, 95%, 90%, and 85% respectively. The overestimation ratios without removing these four bridges are 67%, 95%, 111%, and 122% at confidence levels 99%, 95%, 90%, and 85% respectively.

The bridges are analyzed in this study at operating stress level which is not same as the ultimate capacity level. Hence, overestimation does not necessarily mean failure of the bridge. Based on the allowable stress values used at operating stress level, there will be reserve capacity in the bridges to varying extents depending on the material type of the bridge. For example, the maximum stress in structural steel at operating stress level is only 0.75 F_y. There is at least 33% more capacity available in structural steel bridges beyond the stress level used for structural analysis in this study. There is also an unknown amount of reserve capacity in the bridges that is not utilized due to the limitations of the BARS program during structural analysis. Hence, occasional

overestimation of a minor number of bridges in the sample is tolerable within reasonable limits.

The bridges that are of slab type are analyzed in BARS as if they are just regular rectangular cross sections. Hence, the high overestimation values observed for the group crcs are in part attributed to the limitations of the BARS program. Usually, truss bridges are very efficient in carrying the loads. It is stringers and not the truss elements that are critical for the stt bridge with high overestimation ratios.

4.7 HS truck capacity as a differentiator of weak and strong bridges

Table 4.16 shows the distribution of data points, overestimated by the route independent model, with respect to the HS truck capacity of bridges. The first column "HS truck capacity" contain different classes of HS truck capacity. The second column "Percentage Frequency" show the distribution of bridge sample into various HS truck capacity classes. The rest of the columns under "Percentage Confidence Level" show the percentage data points of the particular class of HS truck capacity that are overestimated by the proposed formulae at the respective confidence levels. The average HS truck capacity of bridges in the sample is HS36.7 (66 tons).

For HS truck capacity less than HS22.2 (40 tons), these bridges are overestimated for all the 17 vehicles with wheel base less than 120 feet for confidence levels 85%, 90% and 95%, and overestimated for 50% of the vehicles at 99% confidence level. We can conclude that the proposed route independent model overestimates almost all bridges with HS truck capacity less than HS22.2 (40 tons) for most of the trucks with wheel base less than 120 feet. Only 1.6% percent of bridges in the sample have HS

truck capacity less than HS22.2 (40 tons).

None of the bridges with HS truck capacity more than HS30.6 (55 tons) are overestimated at 99% confidence level. Nearly 85% of the bridges in the sample have HS truck capacity more than HS30.6 (55 tons). None of the bridges with HS truck capacity greater than HS38.9 (70 tons) in the sample are overestimated even at 85% confidence level. Approximately 37% of the bridges in the sample have HS truck capacity greater than HS38.9 (70 tons).

From these observations, we can conclude that HS truck capacity of a bridge is a good indicator whether that bridge will be overestimated for trucks with wheel base less than 120 feet and greater than 10 feet.

4.8 Analysis of overestimation by the route dependent model

In the previous section, it is clearly shown that HS truck capacity of bridge is a good measure of the performance of the bridge. The bridges that are overestimated are primarily those with low HS truck capacity. Hence, the product of HS truck capacity and the wheel base was studied in a route dependent analysis. This results in an improved model with high quality-of-fit for the data.

The overestimation ratio, OER, is computed for the cases where the confidence limits of the route dependent model overestimate the allowable load. The actual percentage of data that is below various confidence limits, percentage frequency distribution of OER and the maximum OER at various confidence levels is shown in Table 4.17. It can be seen from this table that more than 70% of the overestimated cases have OER value less than 10% and more than 85% of the overestimated cases have OER less than

20%. The maximum overestimation at 99% confidence level is within the acceptable tolerance. If the bridge with NBI number 019937 is excluded, the maximum overestimation ratio is less than 30% at 85% confidence level. With the exception of a few weak bridges, the degree of overestimation is within the tolerable levels.

4.9 Application of route dependent and route independent formulae

From the Sections 4.7 and 4.8, it can be seen that route independent and route dependent models overestimate the allowable loads for a very small fraction of cases. However, the maximum overestimation ratio (OER) is beyond the acceptable tolerance, except for the route dependent model at 99% confidence level. Hence, the route dependent model at 99% confidence level can be used without much concern for the overstressing of the bridges; whereas the other formulae can be used only after addressing the unacceptably high overestimation of the allowable load.

From Table 4.15, the maximum overestimation ratios by the route independent model are 67%, 95%, 111% and 122% at the confidence levels 99%, 95%, 90%, and 85% respectively. Obviously, such excessive overestimation is not acceptable from structural safety point of view. The confidence limits need to be reduced significantly in order to reduce the maximum overestimation to an acceptable level. From Fig. 4.2, this can be achieved only by limiting the truck load to 30 - 40 tons. However, this is highly restrictive and hence abandoned.

It is identified before that the bridges belonging to groups cpcbb, crcs, and stt are overestimated by the route independent formulae. It is also observed that these overestimated bridges exhibit low HS truck capacity values. Hence, the degree of

overestimation by the route independent formulae at different confidence levels for the bridges with HS truck capacities above a certain minimum values is studied and summarized in Table 4.18. It shows that for bridges with HS truck capacity greater than 45 tons the maximum overestimation by the route independent formulae is found to be within acceptable limits at confidence levels 85%, 90%, and 95%. The 99% confidence level route independent formula is acceptable for bridges with HS truck capacity greater than 40 tons. The percentage data that is below various confidence limits also shown in Table 4.18 is less than the expected values. This indicates that the route independent formulae when restricted to bridges with HS truck capacity greater than 45 tons results in improved confidence levels. Hence, the 99% confidence level route independent formula can be used for bridges with HS truck capacity more than 40 tons and the route independent formulae at confidence levels 85%, 90%, or 95% can be used for bridges with HS truck capacity greater than 45 tons, without exceeding the tolerable limits of overestimation of the allowable load.

From these observations, an efficient use of the results of this study can be made through a procedure of evaluation of permits that is route dependent to a certain extent. Initially, INDOT should identify all the highway bridges in the state with HS truck capacity less than 45 tons and 40 tons respectively. The route independent formula at 85%, 90%, or 95% confidence level or the route dependent formula at 99% confidence level can be used, if all the bridges in the route of the permit vehicle have HS truck capacity more than 45 tons. If the least HS truck capacity of the bridges in the

route of the permit truck is greater than 40 tons and less than 45 tons, then use either route independent or route dependent formula at 99% confidence level. If any of the bridges in the route have HS truck capacity less than 40 tons, then use the route dependent formula at 99% confidence level.

At this point of time, INDOT does not have the HS truck capacities for the highway bridges in Indiana. As can be seen from the above description of the proposed permit evaluation procedure, the HS truck capacity of bridges is essential. The INDOT has identified a set of bridges that give low allowable loads for various trucks during BARS analysis. It is recommended that the HS truck capacity be found for all the bridges in the state and then make a list of bridges with low HS truck capacity values. However, until that time at least the currently identified weak bridges should be analyzed for HS truck and their HS truck capacity used in the evaluation of permit trucks.

4.10 Comparison with prior route independent overweight studies

The results obtained from the route independent model is compared with other TTI equations (Noel & James) [4] and the work done by Pucket [3] using a sample of bridges from Wyoming. The data obtained from structural analysis of the sample of Indiana bridges used in this study and the confidence limits of the route independent model that are proposed based on this study are plotted against the previous two studies in Figs 4.59 and 4.60. The mean or 50% confidence limits from Pucket's work is nearly matching with that observed in this study. However, as the confidence level increases, Pucket's work is more restrictive compared to the results of this study. The solution procedure used by Pucket is quite similar to the one used here.

Noel & James approximated the truck loading with a uniform load and used the dead load moment ratios in terms of DL/(LL + I) and design (LL + I) moment and shear data for bridges from various sources in their study. Using this information they estimated the bottom line for allowable moment and shear for bridges with different spans assuming a 5% overstress beyond the design stress level for HS20 designed bridges and 30% overstress for H15 designed bridges. It should be noted that in the current study the bridge analysis is performed at 36% overstress beyond the design stress level or inventory stress level. By comparing the performance of a uniform load of different lengths with the available moment and shear capacities, they had proposed the equations 1.3a and 1.3b for predicting the allowable load, W, in terms of the wheel base, L. The above procedure, when compared to the statistical procedure used in this study, is much more restrictive as it assumes only 5% overstress beyond the design stress level for HS20 designed bridges.

4.11 Summary

The square root transformation of allowable load is applied to satisfy both homogeneity of variance and normality conditions of linear regression analysis. The confidence limits are calculated for both route independent and route dependent models at confidence levels 85%, 90%, 95%, and 99%. These confidence limits are compared with allowable loads of bridges of different groups and material types.

The confidence limits of the route independent model are found to overestimate the allowable load for cpcbb, crcs, and stt bridge groups and underestimate for pcb, kcsg, rcg, rca, and rcs groups. These limits estimate accurately for crcg, csb, csg, kcsb, and

pcbb bridges; while overestimate at lower confidence levels for cpcib, pcib, sb, sg, spt, and kcsb bridge groups. The simple span bridges are found to perform better than continuos span bridges. But this may be due to the limitations of BARS program in structural analysis. It does not consider the negative moment redistribution for continuous spans of prestressed concrete and reinforce concrete bridges.

The confidence limits of the route dependent model overestimate the allowable load for cpcbb, pcbb, and stt groups. They underestimate crcg, kcsb, pcib, rcg, rca, and rcs groups; while predict accurately for cpcib, crcs, csb, kcsg, and pcb bridge groups. No significant differences in the accuracy of prediction between the continuous and simple span bridges are found.

The degree of overstressing by the confidence limits is studied in terms of the overestimation ration (OER). This is useful in selecting the confidence level and formulating an evaluation procedure for use in practice. In general, the number of overstressing cases and the OER values decrease with increasing confidence level. The HS truck capacity of bridges is studied for overestimated cases and is identified as a differentiator of weak and strong bridges. Different formulae are recommended for bridges with different HS truck capacities. For bridges with HS truck capacity less than 40 tons, the route dependent formula at 99% confidence level is recommended. For bridges with HS truck capacity between 40 and 45 tons, either the route dependent or route independent formula at 99% confidence level is recommended. For bridges with HS truck capacity greater than 45 tons, either the route independent formula at 85%, 90%, or 95% confidence level or the route dependent formula at 99% confidence level

is recommended.

The proposed confidence limits of the route independent model are compared with similar studies by Noel & James (1985) and by Pucket (1989). The mean performance of bridges in Indiana is found to be very similar to those in Wyoming. However, the confidence limits for these bridges by Pucket are more restrictive compared to the limits proposed in this study for wheel base greater than 70 feet and less than 120 feet. The equations proposed by Noel and James are even more restrictive, as that study was performed with only 5% overstress for HS20 designed bridges and 30% overstress for H15 designed bridges beyond the design stress level; while the current study is done with 36% overstress beyond design stress level.

In the next chapter, the overall research study will be summarized and a procedure will be described for implementing the results. Finally, the scope for future work will be discussed.

CHAPTER 5

SUMMARY AND IMPLEMENTATION

5.1 Summary

A formula based first phase evaluation of overload permit requests is developed through statistical study of the rating of a representative sample of the highway bridges in Indiana using a representative sample of overload vehicles observed in the past two years (1990 and 1991) in Indiana plus the HS20 design vehicle and the two Indiana Toll Road loadings. A sample of 148 bridges is chosen from the highway bridges using proportionate stratified random sampling process. A sample of 25 trucks, with the truck parameters uniformly distributed over their ranges is compiled. The selected trucks are used to rate bridges in the selected sample using the Bridge Analysis and Rating System (BARS) program at operating stress level. BARS is based on elastic line girder and truss analysis. The allowable load, W, is subjected to linear regression analysis with several bridge and truck parameters as regressor or independent variables.

The wheel base, and the product of HS truck capacity and the wheel base are found to be the best route independent and route dependent regressor variables respectively. The HS capacity of a bridge is defined as the maximum gross vehicle weight that the bridge can carry within operating stress levels for a vehicle having the same configuration in terms of axles and axle weight distribution as the standard HS20 truck

with variable axle spacing. The quality-of-fit is lowered considerably by the data with wheel base greater than 120 feet. Hence, the data is separated into two categories of wheel base less than and greater than 120 feet. For trucks with wheel base greater than 120 feet no significant model is found. Hence, the final results are limited to wheel base less than 120 feet and greater than 10 feet. The square root transformation is applied on the allowable load to achieve a homogeneous variance and also to satisfy the normality assumption of the underlying data in regression analysis. Formulae are developed at 85%, 90%, 95% and 99% confidence levels for both route dependent and route independent models. A practical procedure is formulated for implementation of the results of this study.

5.2 Implementation

The results of both the route dependent and route independent models are restricted to overload trucks with wheel base greater than 10 feet and less than 120 feet. Also the truck must have a minimum of 6 equivalent axles if the wheel base is more than 105 feet, a minimum of 4 equivalent axles if the wheel base is more than 70 feet or a minimum of 3 equivalent axles if the wheel base is more than 25 feet. If the permit truck has wheel base outside the range 10 to 120 feet or has less than the minimum required equivalent axles for its wheel base, then that permit must be sent for detailed analysis of all the bridges in the route of the permit vehicle. These restrictions also apply on the truck configurations recommended for a given gross weight.

The permit truck evaluation can not completely be route independent without being severely restrictive due to some of the very weak highway bridges in the population. As explained in Section 4.9, the route independent model is rendered not useful for practical purposes due to the high overestimation of allowable load experienced by a few weak bridges. Hence, a procedure that is route dependent, but simple, is proposed for the overload permit evaluation. Only one parameter namely HS truck capacity need be extracted from the bridge database for bridges in the route of the permit vehicle in order to evaluate the permit request. This proposed procedure even though somewhat route dependent, should still provide significant savings in time and effort streamlining the current procedure. In addition, it should considerably increase the confidence on its safety and adequacy.

For any given permit request, the list of highway bridges in the route and their HS truck capacities need to be extracted from the bridge database. For the evaluation of bridges with HS truck capacity greater than 45 tons either the route independent formula at confidence level 85%, 90%, 95%, or 99%, or the route dependent formula at 99% confidence level is recommended. For the evaluation bridges with HS truck capacity between 40 tons and 45 tons either the route independent formula or the route dependent formula at 99% confidence level is recommended to be used. For bridges with HS truck capacity less than 40 tons the route dependent formula at 99% confidence level is recommended. A single permit evaluation might involve more than one evaluation of the the proposed formulae. The most critical of these bridge evaluations must be taken as the allowable gross weight for that truck.

Presently, the HS truck capacity is not known for all the bridges in the state. It is highly recommended that this be calculated in order to properly implement the results of this study. The permit division at INDOT has identified a list of bridges that behave weakly for various trucks. At the very least, these bridges should be analyzed with HS truck and checked to determine if any have HS truck capacity less than 45 tons. In the proposed permit procedure, it should be checked if any of these bridges with HS truck capacity less than 45 tons lie in the route of the permit truck. If so, the route dependent formula at 99% confidence level is recommended for evaluation of these particular bridges. For the rest of the bridges, the route independent formula at 85%, 90%, 95%, or 99% can be used for quick evaluation. Eventually, it is recommended that the HS truck capacity be obtained for the highway bridges in the state.

Both procedures, with route independent and route dependent models, are explained below. If a particular permit request does not pass through the criterion set forth in this study, then it must be sent to next phase involving the detailed structural analysis of all the bridges in the route.

5.2.1 Route independent model

The results of route independent model can be used either for judging whether a particular overload permit request can be granted without performing detailed analysis or for specifying a minimum wheel base and a minimum number of equivalent axles required for a given gross weight to be transported, so as to grant the permit for the overload vehicle without performing detailed analysis. In either case, the user must chose one of the confidence levels from the available 85%, 90%, 95%, and 99%.

5.2.1.1 Case 1: Evaluation of a given overload permit request

To evaluate a given overload permit, the wheel base of the overload vehicle should be substituted in the route independent model and the allowable vehicle weight calculated at the chosen confidence level. If the allowable vehicle weight is more than the requested gross load of the permit vehicle, the permit may be granted. Otherwise, the permit request should be forwarded to the next phase for detailed analysis of the bridges.

5.2.1.2 Case 2: Minimum wheel base for a given gross weight

The given gross weight of the overload truck should be substituted as the predicted allowable load in the route independent model at a chosen confidence level and the required wheel base would then be computed. The wheel base of the permit truck must be greater than this to transfer the given overload. If the minimum wheel base required is less than 10 feet, 10 feet should be used as minimum wheel base. If it is more than 120 feet, then no recommendation can be made about the wheel base of the truck. Any truck longer than 120 feet must be analyzed for all bridges in the route. If the wheel base is within 10 feet and 120 feet, any truck which satisfies the minimum wheel base requirement can be granted permission to transport the given gross weight without detailed analysis. The appropriate minimum number of equivalent axles is specified based on the wheel base: - 6 if the wheel base is greater than 105 feet, - 4 if more than 70 feet, - 3 if more than 25 feet.

5.2.2 Route dependent model

To use this model, user must know the route of the permit vehicle and the HS truck capacity of all bridges in the route. Again, this model can be used either for judging whether a particular overload permit request can be granted without performing detailed analysis or for specifying the minimum wheel base and a minimum number of equivalent axles required for a given gross weight so as to grant the permit without detailed analysis. The user must choose a confidence level from the available 85%, 90%, 95%, and 99%.

5.2.2.1 Case 1: Evaluation of a given overload permit request

To evaluate a given overload permit, the lowest HS truck capacity of the bridges in the route and the wheel base should be substituted in the route dependent model and calculate the predicted allowable load at the chosen confidence level. The permit can be granted if the predicted allowable load is greater than the gross weight of the overload vehicle, otherwise the overload vehicle must be sent to next phase for detailed analysis.

5.2.2.2 Case 2: Minimum wheel base for a given gross weight

To determine the minimum wheel base, the minimum HS truck capacity of the bridges in the route and the gross weight are used in the route dependent model for the desired confidence level and the required minimum wheel base is computed. If this is in between 10 feet and 120 feet, then any wheel base between the minimum wheel base and 120 would be permissible for the truck to grant the permit without detailed

analysis. Otherwise, the given gross load with different trucks can be judged only after detailed analysis. The appropriate minimum number of equivalent axles is specified as in Sec. 5.2.1.2.

5.3 Future work

Further study is needed to predict the allowable loads for trucks with wheel base greater than 120 feet. In prior work, Pucket also limited his statistical results to a wheel base of 130 feet. It is interesting to note that the average length of the bridge in the sample of bridges used in this study is about 138 feet. It is possible that for wheel base exceeding 130 feet a considerable part of the truck will be outside the bridge when placed in a critical position, thus making the wheel base a somewhat less relevant parameter. In order to handle such a situation, it would perhaps be necessary to include bridge parameters such as the length of the bridge into the model.

The mean performance of the bridges in Indiana is very much like those in Wyoming. This brings up the issue as to whether the results of this particular study can be extended to other states for overload evaluation. In general, the overload vehicle evaluation depends on the proportion of different types of bridges in state bridge population. For example, for a state with high number of composite prestressed box beam and continuous reinforced concrete slab type bridges, the results of this study may overestimate the allowable loads beyond the acceptable values. Further study is necessary in order to answer this issue.

It is recommended that the HS truck capacity, defined as the maximum vehicle weight for the HS truck configuration at the operating stress level, be determined for stt (steel thru' truss) bridges in the state of Indiana. In these bridges the critical component was found to be not the main longitudinal load carrying trusses, but the longitudinal stringers. It is therefore recommended that a sample of this bridges be instrumented and subjected to control loadings to monitor the actual stresses in the critical elements. This would help to further refine the assumptions in regard to the load distribution used in the rating of this type of bridge. This refinement would be extremely useful to correctly assess the performance of Steel Thru' Truss bridges subjected to overload vehicles. These bridges were shown to be one of the most critical groups of load carrying capacity in this study.

Table 2.1 Classification of bridges into different groups based on structural form, construction and material type

GROUP	*DESCRIPTION*
cpcbb	Continuous Prestressed Concrete Box Beams
cpcib	Continuous Prestressed Concrete I-Beams
crcg	Continuous Reinforced Concrete Girder
crcs	Continuous Reinforced Concrete Slab
csb	Continuous Steel Beam
csg	Continuous Steel Girder (Welded Plate)
kcsb	Composite Continuous Steel Beam
kcsg	Composite Continuous Steel Girder (Welded Plate)
ksb	Composite Steel Beam
pcb	Precast Concrete Beams
pcbb	Prestressed Concrete Box Beams
pcib	Prestressed Concrete I-Beams
rca	Reinforced Concrete Arch
rcg	Reinforced Concrete Girder
rcs	Reinforced Concrete Slab
sb	Simple Steel Beam
sg	Simple Steel Girder
spt	Steel Pony Truss
stt	Steel Thru' Truss

Table 2.2 The distribution of bridge population and sample

GROUP	*Group Size*	*Sample Size*
cpcbb	71	5
cpcib	168	7
crcg	263	10
crcs	613	24
csb	690	23
csg	68	2
kcsb	438	23
kcsg	145	7
ksb	34	1
pcb	75	3
pcbb	285	7
pcib	84	3
rca	50	2
rcg	487	21
rcs	50	3
sb	93	3
sg	12	1
spt	10	1
stt	23	2
Total	3659	148

Table 2.3 The definition of Operating Stress Level

Structural Steel (SS)	$.75\ F_y$
Reinforced Concrete (RC)	
Steel	$.75\ F_y$
Concrete	$.545\ f_c'$
Composite Steel and Concrete (CSC)	
Steel	$.75\ F_y$
Concrete	$.545\ f_c'$
Prestressed Concrete (PSC)	
Steel	$.95\ f_s'$
Concrete	
Compression	$.545\ f_c''$
Tension	$8.16\sqrt{f_c''}$
Composite Prestressed Concrete (CPS)	
Steel	$.95\ f_s'$
Concrete	
Compression	$.545\ f_c''$
Tension	$8.16\sqrt{f_c''}$
Composite Reinforced Concrete (CRC)	
Steel	$.75\ F_y$
Concrete	$.545\ f_c'$

where

F_y = Yield stress of steel.

f_c' = Ultimate strength of concrete - 28 days.

f_s' = Ultimate strength of prestressing strands.

f_c'' = Ultimate strength of concrete in precast prestressed memebers.

Table 2.4 The Description of Database

Item	*Item Description*
Items that are only truck dependent	
Wheel Base, L (ft.)	Distance between first and last axles in ft.
No. of Axles, N	Number of axles in the vehicle
No. of eq. Axles, N_{eq}	Number of equivalent axles
$\bar{x}$ (ft.)	Distance between the front axle and the point of action of the resultant load of the truck.
x_σ (ft.)	The standard deviation of the truck load distribution.
truck_no	Truck number varying from 101 to 125.
Items that are only bridge dependent	
Group	One of the 19 bridge groups shown in Table 2.1.
type	One of the 6 material types identified earlier.
element type	Whether stringer, girder, beam or truss element.
no. spans	Number of spans in the bridge element.
span lengths (ft.)	the lengths of individual spans of the bridge element.
NBI no.	The national bridge inventory number of the bridge.
maxl (ft.)	Longest span length in ft. of the bridge element.
minl (ft.)	Shortest span length in ft. of the bridge element.
Items that are obtained from the BARS analysis	
Allowable Load, W (ton)	Allowable load in tonnes for the given bridge element and truck.
critical span	The span number where the critical point is located.
critical point (ft.)	The distance of the critical point from the nearest left support.
capacity (ft. kips)	The moment capacity of the cross-section at critical point.
dead load eff. (ft. kips)	The moment due to dead load at critical point.
HS truck cap. (ton)	Allowable load of the bridge for an HS truck.

Table 3.1 Coefficient of correlation, r, for route independent simple linear regression models for the prediction of allowable load

Regressor Variable	$10 \le L \le 160$	$10 \le L \le 120$	$120 < L \le 160$ ft.
L	0.75	0.81	0.35
$\bar{x}$	0.73	0.77	0.39
x_σ	0.66	0.79	0.23
N	0.72	0.64	0.62
N_{eq}	0.76	0.74	0.61
$\frac{L\,N}{N-1}$	0.72	0.80	0.09
$\frac{L\,N_{eq}}{N_{eq}-1}$	0.70	0.79	0.20
$\frac{x_\sigma^2}{\bar{x}}$	0.52	0.78	0.40
$L^{2\frac{x_\sigma}{L}}$	0.28	0.69	0.55

Table 3.2 Coefficient of correlation, r, for route independent multiple linear regression models for the prediction of allowable load

Regressor Variables		$10 \le L \le 160$	$10 \le L \le 120$	$120 < L \le 160$ ft.
L	N	0.80	0.81	0.62
L	N_{eq}	0.79	0.81	0.60
$\bar{x}$	N	0.77	0.77	0.63
$\bar{x}$	N_{eq}	0.78	0.78	0.61
L	L^2	0.76	0.82	0.37
$\frac{L\,N}{N-1}$	N	0.79	0.81	0.63
$\frac{L\,N_{eq}}{N_{eq}-1}$	N_{eq}	0.79	0.81	0.60
x_σ	$L^{2\frac{x_\sigma}{L}}$	0.80	0.80	0.61
L	x_σ	0.80	0.80	0.60
x_σ	x_σ^2	0.71	0.80	0.29

Table 3.3 Coefficient of correlation, r, for route dependent simple linear regression models for the prediction of allowable load

Regressor Variable	$10 \le L \le 160$	$10 \le L \le 120$	$120 < L \le 160$ft.
No_spans	0.15	0.14	0.24
$\frac{maxl}{minl}$	0.06	0.05	0.09
bridge length	0.10	0.09	0.18
$\frac{x_\sigma}{\bar{x}}$ maxl	0.12	0.15	0.23
$\frac{\bar{x}}{maxl}$	0.59	0.60	0.25
$\frac{x_\sigma^2}{maxl}$	0.52	0.69	0.00
$\frac{x_\sigma^2}{\bar{x}}$	0.52	0.78	0.40
$\frac{x_\sigma^2}{maxl-\bar{x}}$	0.02	0.01	0.00
$\frac{maxl-x_\sigma}{\bar{x}}$	0.47	0.49	0.06
Abs $\left[\frac{x_\sigma}{\left(\frac{maxl+minl}{2}\right)} - 1\right]$	0.36	0.60	0.01
$\frac{x_\sigma}{\left(\frac{maxl+minl}{2}\right)}$	0.53	0.60	0.04
Abs $\left[\frac{2\,x_\sigma}{\left(\frac{maxl+minl}{2}\right)} - 1\right]$	0.30	0.14	0.04
HS truck cap.×L	0.86	0.92	0.68
HS truck cap.×N	0.84	0.77	0.83
HS truck cap.×N_{eq}	0.85	0.82	0.83

Table 3.4 Coefficient of correlation, r, for route dependent multiple linear regression models for the prediction of allowable load

Regressor Variables		$10 \le L \le 160$	$10 \le L \le 120$	$120 < L \le 160$ ft.
HS cap.×L	HS cap.×N	0.91	0.92	0.85
HS cap.×L	HS cap.×N_{eq}	0.91	0.93	0.83

Table 3.5 Coefficient of correlation, r, for two simple linear regression models for the prediction of allowable load for different groups of bridges and for trucks with $10 \le L \le 120$ ft.

Group	*L*	HS truck cap. × L
cpcbb	0.76	0.89
cpcib	0.86	0.94
crcg	0.89	0.94
crcs	0.82	0.92
csb	0.88	0.94
csg	0.88	0.96
kcsb	0.88	0.95
kcsg	0.86	0.94
ksb	0.96	0.96
pcb	0.89	0.88
pcbb	0.79	0.93
pcib	0.92	0.94
rca	0.88	0.91
rcg	0.90	0.92
rcs	0.83	0.89
sb	0.91	0.95
sg	0.97	0.96
spt	0.95	0.97
stt	0.80	0.94

Table 3.6 Restrictions on number of equivalent axles of overload vehicle for a given wheel base

Wheel Base (ft.)	*Minimum* N_{eq}
>25	3
>70	4
>105	6

Table 4.1 Summary of Route Independent Model $\sqrt{W} = c_1\ L + c_2$ for trucks with $10 \le L \le 120$ ft.

c_1 (coeff.)	0.0484 ($ton^{1/2}$/ft.)
c_2 (intercept)	6.891 ($ton^{1/2}$)
σ_{in} for individual prediction	1.031 ($ton^{1/2}$)
r, coefficient of Correlation	0.830
$W^{1/2}$ ($ton^{1/2}$) at 50%	0.0484 L + 6.891
$W^{1/2}$ ($ton^{1/2}$) at 85%	0.0484 L + 5.822
$W^{1/2}$ ($ton^{1/2}$) at 90%	0.0484 L + 5.570
$W^{1/2}$ ($ton^{1/2}$) at 95%	0.0484 L + 5.195
$W^{1/2}$ ($ton^{1/2}$) at 99%	0.0484 L + 4.493
W (ton) at 50%	$2.34\text{x}10^{-3}\ L^2 + 0.667\ L + 47.48$
W (ton) at 85%	$2.34\text{x}10^{-3}\ L^2 + 0.564\ L + 33.90$
W (ton) at 90%	$2.34\text{x}10^{-3}\ L^2 + 0.539\ L + 31.02$
W (ton) at 95%	$2.34\text{x}10^{-3}\ L^2 + 0.503\ L + 26.99$
W (ton) at 99%	$2.34\text{x}10^{-3}\ L^2 + 0.435\ L + 20.19$

Table 4.2 Summary of Route Dependent Model
$\sqrt{W} = c_1$ HS truck cap. x L + c_2 for trucks with $10 \le L \le 120$ ft.

c_1 (coeff.)	$7.495\text{x}10^{-4}\ \frac{ton^{-\frac{1}{2}}}{ft.}$
c_2 (intercept)	6.795 ($ton^{1/2}$)
σ_{in} for individual prediction	0.686 ($ton^{1/2}$)
r, coefficient of Correlation	0.93
$W^{1/2}$($ton^{1/2}$) at 50%	$7.495\text{x}10^{-4}$ HS truck cap. × L + 6.795
$W^{1/2}$($ton^{1/2}$) at 85%	$7.495\text{x}10^{-4}$ HS truck cap. × L + 6.084
$W^{1/2}$($ton^{1/2}$) at 90%	$7.495\text{x}10^{-4}$ HS truck cap. × L + 5.916
$W^{1/2}$($ton^{1/2}$) at 95%	$7.495\text{x}10^{-4}$ HS truck cap. × L + 5.667
$W^{1/2}$($ton^{1/2}$) at 99%	$7.495\text{x}10^{-4}$ HS truck cap. × L + 5.200

Table 4.3 The percentage of data that is below the confidence limits of the route independent model at 50%, 85%, 90%, 95%, and 99% confidence levels for the test sample of bridges

Confidence Level (%)	*% data points below confidence limit*
50	60.0
85	16.0
90	6.7
95	4.7
99	0.0

Table 4.4 The percentage of data that is below the confidence limits of the route dependent model at 50%, 85%, 90%, 95%, and 99% confidence levels for the test sample of bridges

Confidence Level (%)	*% data points below confidence limit*
50	49.0
85	15.0
90	9.0
95	6.0
99	0.7

Table 4.5 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for each group of bridges and all bridges for route independent model

GROUP	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
cpcbb	3.4	83.9	58.6	47.1	25.3	9.2
cpcib	4.8	62.5	16.7	10.0	4.2	1.7
crcg	6.7	47.6	10.0	5.9	2.4	0.0
crcs	16.2	67.4	18.6	11.8	7.6	4.2
csb	15.5	56.8	12.3	7.4	2.8	0.3
csg	1.3	52.9	11.8	8.8	0.0	0.0
kcsb	15.5	57.3	5.6	1.5	0.5	0.0
kcsg	4.7	32.8	2.5	0.8	0.0	0.0
ksb	0.7	100.0	35.3	17.6	5.9	0.0
pcb	2.0	0.0	0.0	0.0	0.0	0.0
pcbb	4.8	57.4	10.7	6.6	3.3	0.0
pcib	2.0	62.7	7.8	3.9	0.0	0.0
rca	1.3	20.6	0.0	0.0	0.0	0.0
rcg	14.2	7.8	0.0	0.0	0.0	0.0
rcs	2.0	31.4	3.9	0.0	0.0	0.0
sb	2.0	84.3	17.6	7.8	3.9	0.0
sg	0.7	94.1	5.9	0.0	0.0	0.0
spt	0.7	94.1	17.6	0.0	0.0	0.0
stt	1.3	100.0	76.5	64.7	52.9	35.3
All Groups	100.0	51.0	12.1	7.5	4.0	1.6

Table 4.6 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for each material type of bridges using route independent model

Material	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
CPS & PSC	15.1	65.8	23.2	16.6	8.2	2.2
CSC	20.9	56.9	5.9	1.9	0.6	0.0
RC	42.5	38.0	8.9	5.4	3.3	1.6
SS	21.6	64.2	16.7	10.7	5.7	2.4

Table 4.7 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for continuous and simple span bridges for route independent model

Continuity	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
Simple Span	31.8	34.8	8.0	4.9	3.1	1.5
Continuous Span	68.2	59.7	14.0	8.7	4.4	1.6

Table 4.8 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for each group of bridges and all bridges for route dependent model

GROUP	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
cpcbb	3.4	83.9	51.7	40.2	26.4	8.0
cpcib	4.8	57.5	15.0	10.0	2.5	0.8
crcg	6.7	31.2	5.9	3.5	0.6	0.0
crcs	16.2	54.7	12.5	5.9	3.9	2.5
csb	15.5	50.1	11.8	6.9	1.3	0.3
csg	1.3	76.5	20.6	14.7	2.9	0.0
kcsb	15.5	61.9	12.5	6.1	2.8	0.0
kcsg	4.7	56.3	18.5	10.9	4.2	0.0
Ksb	0.7	94.1	11.8	11.8	5.9	0.0
pcb	2.0	33.3	15.7	11.8	5.9	2.0
pcbb	4.8	68.0	25.4	18.0	9.8	3.3
pcib	2.0	60.8	5.9	2.0	2.0	0.0
rca	1.3	38.2	11.8	8.8	5.9	0.0
rcg	14.2	21.8	5.0	2.8	1.7	0.0
rcs	2.0	37.3	11.8	5.9	0.0	0.0
sb	2.0	62.7	9.8	5.9	3.9	0.0
sg	0.7	88.2	11.8	11.8	11.8	0.0
spt	0.7	88.2	17.6	11.8	0.0	0.0
stt	1.3	88.2	52.9	44.1	38.2	14.7
All Groups	100.0	51.4	13.8	8.5	4.2	1.1

Table 4.9 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for each material type of bridges for the route dependent model

Material	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
CPS & PSC	15.1	67.1	25.5	18.4	10.3	3.2
CSC	20.9	61.7	13.9	7.4	3.2	0.0
RC	42.5	37.6	9.1	5.0	2.6	1.0
SS	21.6	57.7	14.9	9.6	4.2	1.1

Table 4.10 The Percentage distribution of data points that lie below the confidence limits 50%, 85%, 90%, 95%, and 99% for continuous and simple span bridges for the route dependent model

Continuity	*% Data Points*	*% Confidence Levels*				
		50%	*85%*	*90%*	*95%*	*99%*
Simple Span	31.8	43.4	12.5	8.6	5.2	1.2
Continuous Span	68.2	55.2	14.4	8.5	3.8	1.1

Table 4.11 The list of bridges that are overestimated by the route independent model at 85% confidence level for trucks with 10 ≤ L ≤ 120 ft.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
1	013080	102	cpcbb	3	40.00	24.00	88.00	22.00	47.20	47.43	0.5
2	013080	106	cpcbb	3	40.00	24.00	88.00	27.00	47.70	50.83	6.6
3	013080	125	cpcbb	3	40.00	24.00	88.00	28.00	48.30	51.52	6.7
4	013080	103	cpcbb	3	40.00	24.00	88.00	47.50	59.50	65.96	10.9
5	013080	107	cpcbb	3	40.00	24.00	88.00	58.47	65.40	74.86	14.5
6	013080	111	cpcbb	3	40.00	24.00	88.00	60.18	59.70	76.30	27.8
7	013080	104	cpcbb	3	40.00	24.00	88.00	67.57	82.00	82.68	0.8
8	013080	124	cpcbb	3	40.00	24.00	88.00	76.00	78.10	90.27	15.6
9	013080	116	cpcbb	3	40.00	24.00	88.00	82.00	86.00	95.87	11.5
10	013080	108	cpcbb	3	40.00	24.00	88.00	82.00	84.00	95.87	14.1
11	013080	112	cpcbb	3	40.00	24.00	88.00	85.49	87.60	99.20	13.2
12	013080	122	cpcbb	3	40.00	24.00	88.00	99.83	106.20	113.51	06.9
13	013080	109	cpcbb	3	40.00	24.00	88.00	101.50	87.10	115.24	32.3
14	013080	113	cpcbb	3	40.00	24.00	88.00	102.90	107.10	116.70	09.0
15	013080	119	cpcbb	3	40.00	24.00	88.00	117.36	116.80	132.31	13.3
16	021130	124	cpcbb	2	40.00	40.00	80.00	76.00	50.20	90.27	79.8
17	021130	122	cpcbb	2	40.00	40.00	80.00	99.83	69.30	113.51	63.8
18	026520	101	cpcbb	3	48.50	47.75	144.00	11.58	31.10	40.74	31.0
19	026520	102	cpcbb	3	48.50	47.75	144.00	22.00	33.40	47.43	42.0
20	026520	106	cpcbb	3	48.50	47.75	144.00	27.00	34.60	50.83	46.9
21	026520	125	cpcbb	3	48.50	47.75	144.00	28.00	43.88	51.52	17.4
22	026520	123	cpcbb	3	48.50	47.75	144.00	28.00	39.00	51.52	32.1
23	026520	103	cpcbb	3	48.50	47.75	144.00	47.50	56.20	65.96	17.4
24	026520	107	cpcbb	3	48.50	47.75	144.00	58.47	59.70	74.86	25.4
25	026520	111	cpcbb	3	48.50	47.75	144.00	60.18	56.50	76.30	35.0
26	026520	104	cpcbb	3	48.50	47.75	144.00	67.57	62.80	82.68	31.7
27	026520	124	cpcbb	3	48.50	47.75	144.00	76.00	72.00	90.27	25.4
28	026520	116	cpcbb	3	48.50	47.75	144.00	82.00	70.20	95.87	36.6
29	026520	108	cpcbb	3	48.50	47.75	144.00	82.00	67.50	95.87	42.0
30	026520	112	cpcbb	3	48.50	47.75	144.00	85.49	74.40	99.20	33.3

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
31	026520	122	cpcbb	3	48.50	47.75	144.00	99.83	84.00	113.51	35.1
32	026520	109	cpcbb	3	48.50	47.75	144.00	101.50	73.90	115.24	55.9
33	026520	113	cpcbb	3	48.50	47.75	144.00	102.90	91.20	116.70	28.0
34	026520	119	cpcbb	3	48.50	47.75	144.00	117.36	111.40	132.31	18.8
35	027150	107	cpcbb	3	44.00	44.00	132.00	58.47	70.10	74.86	06.8
36	027150	111	cpcbb	3	44.00	44.00	132.00	60.18	75.70	76.30	0.8
37	027150	104	cpcbb	3	44.00	44.00	132.00	67.57	75.40	82.68	09.7
38	027150	124	cpcbb	3	44.00	44.00	132.00	76.00	84.70	90.27	06.6
39	027150	116	cpcbb	3	44.00	44.00	132.00	82.00	84.70	95.87	13.2
40	027150	108	cpcbb	3	44.00	44.00	132.00	82.00	83.00	95.87	15.5
41	027150	112	cpcbb	3	44.00	44.00	132.00	85.49	92.60	99.20	07.1
42	027150	122	cpcbb	3	44.00	44.00	132.00	99.83	108.80	113.51	04.3
43	027450	107	cpcbb	5	48.50	47.75	241.00	58.47	74.10	74.86	01.0
44	027450	104	cpcbb	5	48.50	47.75	241.00	67.57	77.60	82.68	06.5
45	027450	124	cpcbb	5	48.50	47.75	241.00	76.00	88.40	90.27	02.1
46	027450	116	cpcbb	5	48.50	47.75	241.00	82.00	88.50	95.87	08.3
47	027450	108	cpcbb	5	48.50	47.75	241.00	82.00	84.80	95.87	13.1
48	027450	112	cpcbb	5	48.50	47.75	241.00	85.49	93.80	99.20	05.8
49	027450	122	cpcbb	5	48.50	47.75	241.00	99.83	106.20	113.51	06.9
50	027450	109	cpcbb	5	48.50	47.75	241.00	101.50	114.90	115.24	0.3
51	027450	113	cpcbb	5	48.50	47.75	241.00	102.90	115.60	116.70	01.0
52	015930	109	cpcib	3	40.00	35.00	110.00	101.50	108.80	115.24	05.9
53	022770	102	cpcib	5	75.00	62.50	325.00	22.00	46.60	47.43	01.8
54	022770	106	cpcib	5	75.00	62.50	325.00	27.00	47.40	50.83	07.2
55	022770	123	cpcib	5	75.00	62.50	325.00	28.00	51.30	51.52	0.4
56	022770	111	cpcib	5	75.00	62.50	325.00	60.18	67.90	76.30	12.4
57	022770	108	cpcib	5	75.00	62.50	325.00	82.00	83.40	95.87	14.9
58	022770	112	cpcib	5	75.00	62.50	325.00	85.49	92.00	99.20	07.8
59	022770	122	cpcib	5	75.00	62.50	325.00	99.83	103.10	113.51	10.1
60	022770	109	cpcib	5	75.00	62.50	325.00	101.50	87.80	115.24	31.3

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
61	022770	113	cpcib	5	75.00	62.50	325.00	102.90	110.20	116.70	05.9
62	022770	119	cpcib	5	75.00	62.50	325.00	117.36	127.40	132.31	03.9
63	024835	102	cpcib	3	43.50	42.75	129.00	22.00	44.40	47.43	06.8
64	024835	106	cpcib	3	43.50	42.75	129.00	27.00	46.50	50.83	09.3
65	024835	108	cpcib	3	43.50	42.75	129.00	82.00	89.00	95.87	07.7
66	024835	112	cpcib	3	43.50	42.75	129.00	85.49	95.00	99.20	04.4
67	024835	109	cpcib	3	43.50	42.75	129.00	101.50	94.20	115.24	22.3
68	029940	111	cpcib	3	71.50	70.75	213.00	60.18	73.80	76.30	03.4
69	029940	108	cpcib	3	71.50	70.75	213.00	82.00	94.30	95.87	01.7
70	029940	109	cpcib	3	71.50	70.75	213.00	101.50	98.30	115.24	17.2
71	037930	125	cpcib	4	100.50	33.50	268.00	28.00	31.14	51.52	65.4
72	014750	101	crcg	3	63.00	47.00	157.00	11.58	40.00	40.74	01.9
73	014750	102	crcg	3	63.00	47.00	157.00	22.00	42.90	47.43	10.6
74	014750	106	crcg	3	63.00	47.00	157.00	27.00	45.80	50.83	11.0
75	014750	107	crcg	3	63.00	47.00	157.00	58.47	68.10	74.86	09.9
76	014750	111	crcg	3	63.00	47.00	157.00	60.18	70.90	76.30	07.6
77	014750	104	crcg	3	63.00	47.00	157.00	67.57	74.80	82.68	10.5
78	014750	124	crcg	3	63.00	47.00	157.00	76.00	89.40	90.27	01.0
79	014750	116	crcg	3	63.00	47.00	157.00	82.00	83.60	95.87	14.7
80	014750	108	crcg	3	63.00	47.00	157.00	82.00	79.40	95.87	20.7
81	014750	112	crcg	3	63.00	47.00	157.00	85.49	82.10	99.20	20.8
82	014750	122	crcg	3	63.00	47.00	157.00	99.83	109.40	113.51	03.8
83	014750	109	crcg	3	63.00	47.00	157.00	101.50	90.90	115.24	26.8
84	014750	113	crcg	3	63.00	47.00	157.00	102.90	113.20	116.70	03.1
85	014750	119	crcg	3	63.00	47.00	157.00	117.36	131.60	132.31	0.5
86	034280	109	crcg	3	56.00	43.00	142.00	101.50	104.40	115.24	10.4
87	041600	109	crcg	4	71.25	39.00	220.50	101.50	113.30	115.24	01.7
88	042700	109	crcg	3	60.00	45.00	150.00	101.50	115.10	115.24	0.1
89	004740	116	crcs	3	25.00	19.00	63.00	82.00	95.70	95.87	0.2
90	004740	108	crcs	3	25.00	19.00	63.00	82.00	93.40	95.87	02.6

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
91	004740	109	crcs	3	25.00	19.00	63.00	101.50	105.30	115.24	09.4
92	008230	101	crcs	3	32.00	24.00	80.00	11.58	40.30	40.74	01.1
93	008230	102	crcs	3	32.00	24.00	80.00	22.00	45.10	47.43	05.2
94	008230	106	crcs	3	32.00	24.00	80.00	27.00	49.40	50.83	02.9
95	008230	125	crcs	3	32.00	24.00	80.00	28.00	47.90	51.52	07.6
96	008230	107	crcs	3	32.00	24.00	80.00	58.47	69.20	74.86	08.2
97	008230	104	crcs	3	32.00	24.00	80.00	67.57	73.90	82.68	11.9
98	008230	116	crcs	3	32.00	24.00	80.00	82.00	84.80	95.87	13.1
99	008230	108	crcs	3	32.00	24.00	80.00	82.00	80.50	95.87	19.1
100	008230	112	crcs	3	32.00	24.00	80.00	85.49	83.80	99.20	18.4
101	008230	109	crcs	3	32.00	24.00	80.00	101.50	96.80	115.24	19.0
102	013100	108	crcs	3	30.00	22.50	75.00	82.00	94.60	95.87	01.3
103	013100	122	crcs	3	30.00	22.50	75.00	99.83	112.30	113.51	01.1
104	013100	109	crcs	3	30.00	22.50	75.00	101.50	96.10	115.24	19.9
105	019937	101	crcs	3	29.00	21.75	72.50	11.58	21.80	40.74	86.9
106	019937	102	crcs	3	29.00	21.75	72.50	22.00	25.70	47.43	84.6
107	019937	106	crcs	3	29.00	21.75	72.50	27.00	26.00	50.83	95.5
108	019937	123	crcs	3	29.00	21.75	72.50	28.00	33.00	51.52	56.1
109	019937	125	crcs	3	29.00	21.75	72.50	28.00	27.25	51.52	89.0
110	019937	103	crcs	3	29.00	21.75	72.50	47.50	48.30	65.96	36.6
111	019937	107	crcs	3	29.00	21.75	72.50	58.47	36.70	74.86	104.0
112	019937	111	crcs	3	29.00	21.75	72.50	60.18	45.40	76.30	68.1
113	019937	104	crcs	3	29.00	21.75	72.50	67.57	42.10	82.68	96.4
114	019937	124	crcs	3	29.00	21.75	72.50	76.00	52.70	90.27	71.3
115	019937	108	crcs	3	29.00	21.75	72.50	82.00	68.70	95.87	39.5
116	019937	116	crcs	3	29.00	21.75	72.50	82.00	46.80	95.87	104.8
117	019937	112	crcs	3	29.00	21.75	72.50	85.49	44.70	99.20	121.9
118	019937	122	crcs	3	29.00	21.75	72.50	99.83	79.60	113.51	42.6
119	019937	109	crcs	3	29.00	21.75	72.50	101.50	65.60	115.24	75.7
120	019937	113	crcs	3	29.00	21.75	72.50	102.90	70.90	116.70	64.6

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
121	019937	119	crcs	3	29.00	21.75	72.50	117.36	94.30	132.31	40.3
122	021600	109	crcs	3	45.50	32.50	110.50	101.50	99.20	115.24	16.2
123	028370	107	crcs	3	36.00	27.00	90.00	58.47	74.30	74.86	0.8
124	028370	111	crcs	3	36.00	27.00	90.00	60.18	72.70	76.30	05.0
125	028370	124	crcs	3	36.00	27.00	90.00	76.00	88.10	90.27	02.5
126	028370	109	crcs	3	36.00	27.00	90.00	101.50	98.80	115.24	16.6
127	037960	109	crcs	3	35.00	25.00	85.00	101.50	104.70	115.24	10.1
128	038320	102	crcs	3	36.00	27.00	90.00	22.00	47.00	47.43	0.9
129	038320	106	crcs	3	36.00	27.00	90.00	27.00	46.80	50.83	08.6
130	038320	125	crcs	3	36.00	27.00	90.00	28.00	47.43	51.52	08.6
131	038320	112	crcs	3	36.00	27.00	90.00	85.49	88.10	99.20	12.6
132	038320	109	crcs	3	36.00	27.00	90.00	101.50	98.00	115.24	17.6
133	038320	113	crcs	3	36.00	27.00	90.00	102.90	115.40	116.70	01.1
134	039600	107	crcs	3	47.33	36.33	119.99	58.47	73.30	74.86	02.1
135	039600	104	crcs	3	47.33	36.33	119.99	67.57	78.10	82.68	05.9
136	039600	124	crcs	3	47.33	36.33	119.99	76.00	90.20	90.27	0.1
137	039600	116	crcs	3	47.33	36.33	119.99	82.00	92.00	95.87	04.2
138	039600	108	crcs	3	47.33	36.33	119.99	82.00	84.50	95.87	13.5
139	039600	112	crcs	3	47.33	36.33	119.99	85.49	97.80	99.20	01.4
140	039600	109	crcs	3	47.33	36.33	119.99	101.50	110.70	115.24	04.1
141	039800	102	crcs	3	20.00	16.00	52.00	22.00	44.80	47.43	05.9
142	039800	125	crcs	3	20.00	16.00	52.00	28.00	42.91	51.52	20.1
143	039800	103	crcs	3	20.00	16.00	52.00	47.50	63.00	65.96	04.7
144	039800	107	crcs	3	20.00	16.00	52.00	58.47	71.90	74.86	04.1
145	039800	104	crcs	3	20.00	16.00	52.00	67.57	76.60	82.68	07.9
146	039800	116	crcs	3	20.00	16.00	52.00	82.00	87.50	95.87	09.6
147	039800	108	crcs	3	20.00	16.00	52.00	82.00	81.30	95.87	17.9
148	039800	112	crcs	3	20.00	16.00	52.00	85.49	89.90	99.20	10.3
149	039800	122	crcs	3	20.00	16.00	52.00	99.83	97.20	113.51	16.8
150	039800	109	crcs	3	20.00	16.00	52.00	101.50	82.60	115.24	39.5

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
151	039800	113	crcs	3	20.00	16.00	52.00	102.90	98.70	116.70	18.2
152	039800	119	crcs	3	20.00	16.00	52.00	117.36	127.20	132.31	04.0
153	039970	125	crcs	3	28.00	21.00	70.00	28.00	49.99	51.52	03.1
154	039970	108	crcs	3	28.00	21.00	70.00	82.00	87.00	95.87	10.2
155	039970	122	crcs	3	28.00	21.00	70.00	99.83	102.80	113.51	10.4
156	039970	109	crcs	3	28.00	21.00	70.00	101.50	89.60	115.24	28.6
157	039970	113	crcs	3	28.00	21.00	70.00	102.90	113.20	116.70	03.1
158	041340	109	crcs	3	41.50	32.00	105.50	101.50	100.90	115.24	14.2
159	044430	109	crcs	4	44.75	37.25	164.00	101.50	112.60	115.24	02.3
160	049330	106	crcs	3	40.00	30.00	100.00	27.00	47.90	50.83	06.1
161	049330	125	crcs	3	40.00	30.00	100.00	28.00	49.59	51.52	03.9
162	049330	108	crcs	3	40.00	30.00	100.00	82.00	92.90	95.87	03.2
163	049330	112	crcs	3	40.00	30.00	100.00	85.49	99.10	99.20	0.1
164	049330	109	crcs	3	40.00	30.00	100.00	101.50	98.30	115.24	17.2
165	000970	109	csb	2	67.50	67.50	135.00	101.50	107.40	115.24	07.3
166	009160	109	csb	5	78.00	63.00	360.00	101.50	112.00	115.24	02.9
167	015450	122	csb	3	85.00	68.00	221.00	99.83	113.50	113.51	0.0
168	015450	109	csb	3	85.00	68.00	221.00	101.50	107.20	115.24	07.5
169	015450	113	csb	3	85.00	68.00	221.00	102.90	112.40	116.70	03.8
170	015450	119	csb	3	85.00	68.00	221.00	117.36	130.70	132.31	01.2
171	015550	109	csb	3	92.00	74.00	240.00	101.50	110.00	115.24	04.8
172	015550	113	csb	3	92.00	74.00	240.00	102.90	115.50	116.70	01.0
173	022600	101	csb	2	70.00	70.00	140.00	11.58	40.30	40.74	01.1
174	022600	102	csb	2	70.00	70.00	140.00	22.00	42.60	47.43	11.3
175	022600	106	csb	2	70.00	70.00	140.00	27.00	43.30	50.83	17.4
176	022600	123	csb	2	70.00	70.00	140.00	28.00	46.60	51.52	10.6
177	022600	125	csb	2	70.00	70.00	140.00	28.00	44.69	51.52	15.3
178	022600	103	csb	2	70.00	70.00	140.00	47.50	59.30	65.96	11.2
179	022600	107	csb	2	70.00	70.00	140.00	58.47	68.40	74.86	09.4
180	022600	111	csb	2	70.00	70.00	140.00	60.18	59.00	76.30	29.3

Table 4.11 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
181	022600	104	csb	2	70.00	70.00	140.00	67.57	78.30	82.68	05.6
182	022600	124	csb	2	70.00	70.00	140.00	76.00	84.60	90.27	06.7
183	022600	116	csb	2	70.00	70.00	140.00	82.00	88.50	95.87	08.3
184	022600	108	csb	2	70.00	70.00	140.00	82.00	74.30	95.87	29.0
185	022600	112	csb	2	70.00	70.00	140.00	85.49	85.20	99.20	16.4
186	022600	122	csb	2	70.00	70.00	140.00	99.83	91.00	113.51	24.7
187	022600	109	csb	2	70.00	70.00	140.00	101.50	78.10	115.24	47.6
188	022600	113	csb	2	70.00	70.00	140.00	102.90	100.60	116.70	16.0
189	022600	119	csb	2	70.00	70.00	140.00	117.36	115.60	132.31	14.5
190	038180	116	csb	3	62.00	37.00	136.00	82.00	91.70	95.87	04.5
191	038180	108	csb	3	62.00	37.00	136.00	82.00	87.70	95.87	09.3
192	038180	122	csb	3	62.00	37.00	136.00	99.83	108.10	113.51	05.0
193	038180	109	csb	3	62.00	37.00	136.00	101.50	109.10	115.24	05.6
194	038470	108	csb	3	60.00	49.00	158.00	82.00	88.00	95.87	08.9
195	038470	112	csb	3	60.00	49.00	158.00	85.49	97.10	99.20	02.2
196	038470	109	csb	3	60.00	49.00	158.00	101.50	96.50	115.24	19.4
197	043400	109	csb	5	60.00	50.00	280.00	101.50	109.60	115.24	05.1
198	044090	109	csb	3	72.00	60.00	192.00	101.50	104.20	115.24	10.6
199	045330	109	csb	3	45.50	35.00	115.50	101.50	113.50	115.24	01.5
200	049050	102	csb	3	53.00	44.50	142.00	22.00	46.50	47.43	02.0
201	049050	106	csb	3	53.00	44.50	142.00	27.00	48.10	50.83	05.7
202	049050	125	csb	3	53.00	44.50	142.00	28.00	50.35	51.52	02.3
203	049050	107	csb	3	53.00	44.50	142.00	58.47	73.30	74.86	02.1
204	049050	111	csb	3	53.00	44.50	142.00	60.18	72.90	76.30	04.7
205	049050	104	csb	3	53.00	44.50	142.00	67.57	79.90	82.68	03.5
206	049050	116	csb	3	53.00	44.50	142.00	82.00	93.00	95.87	03.1
207	049050	108	csb	3	53.00	44.50	142.00	82.00	81.50	95.87	17.6
208	049050	112	csb	3	53.00	44.50	142.00	85.49	88.90	99.20	11.6
209	049050	122	csb	3	53.00	44.50	142.00	99.83	107.80	113.51	05.3
210	049050	109	csb	3	53.00	44.50	142.00	101.50	90.80	115.24	26.9

Table 4.11 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
211	050870	108	csb	3	66.00	55.00	176.00	82.00	93.00	95.87	03.1
212	050870	109	csb	3	66.00	55.00	176.00	101.50	100.40	115.24	14.8
213	050320	111	csg	6	111.00	88.00	620.00	60.18	71.50	76.30	06.7
214	050320	108	csg	6	111.00	88.00	620.00	82.00	89.30	95.87	07.4
215	050320	122	csg	6	111.00	88.00	620.00	99.83	112.80	113.51	0.6
216	050320	109	csg	6	111.00	88.00	620.00	101.50	104.40	115.24	10.4
217	015200	109	kcsb	3	57.00	45.00	147.00	101.50	114.00	115.24	01.1
218	041870	109	kcsb	3	83.50	69.75	223.00	101.50	109.10	115.24	05.6
219	041970	122	kcsb	2	63.00	63.00	126.00	99.83	113.50	113.51	0.0
220	041970	109	kcsb	2	63.00	63.00	126.00	101.50	112.10	115.24	02.8
221	042430	109	kcsb	3	52.25	34.50	121.25	101.50	114.20	115.24	0.9
222	042470	106	kcsb	4	74.90	40.00	243.00	27.00	49.40	50.83	02.9
223	042470	125	kcsb	4	74.90	40.00	243.00	28.00	51.39	51.52	0.2
224	042470	111	kcsb	4	74.90	40.00	243.00	60.18	68.40	76.30	11.6
225	042470	108	kcsb	4	74.90	40.00	243.00	82.00	89.60	95.87	07.0
226	042470	122	kcsb	4	74.90	40.00	243.00	99.83	108.70	113.51	04.4
227	042470	109	kcsb	4	74.90	40.00	243.00	101.50	98.50	115.24	17.0
228	042470	113	kcsb	4	74.90	40.00	243.00	102.90	111.50	116.70	04.7
229	042470	119	kcsb	4	74.90	40.00	243.00	117.36	131.40	132.31	0.7
230	049120	109	kcsb	3	84.75	48.50	188.75	101.50	111.40	115.24	03.4
231	049120	113	kcsb	3	84.75	48.50	188.75	102.90	115.80	116.70	0.8
232	050440	111	kcsb	2	74.00	74.00	148.00	60.18	70.50	76.30	8.2
233	050440	108	kcsb	2	74.00	74.00	148.00	82.00	91.60	95.87	04.7
234	050440	112	kcsb	2	74.00	74.00	148.00	85.49	98.00	99.20	01.2
235	050440	122	kcsb	2	74.00	74.00	148.00	99.83	112.60	113.51	0.8
236	050440	109	kcsb	2	74.00	74.00	148.00	101.50	99.80	115.24	15.5
237	050440	113	kcsb	2	74.00	74.00	148.00	102.90	113.70	116.70	02.6
238	050550	109	kcsb	2	78.50	78.50	157.00	101.50	110.70	115.24	04.1
239	034290	108	kcsg	3	89.00	32.00	161.00	82.00	94.90	95.87	01.0
240	034290	112	kcsg	3	89.00	32.00	161.00	85.49	98.10	99.20	01.1

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
241	034290	109	kcsg	3	89.00	32.00	161.00	101.50	108.00	115.24	06.7
242	036030	111	ksb	1	80.25	80.25	80.25	60.18	68.00	76.30	12.2
243	036030	108	ksb	1	80.25	80.25	80.25	82.00	90.00	95.87	06.5
244	036030	122	ksb	1	80.25	80.25	80.25	99.83	108.30	113.51	04.8
245	036030	109	ksb	1	80.25	80.25	80.25	101.50	93.20	115.24	23.6
246	036030	113	ksb	1	80.25	80.25	80.25	102.90	113.70	116.70	02.6
247	036030	119	ksb	1	80.25	80.25	80.25	117.36	130.90	132.31	01.1
248	001530	111	pcbb	1	70.00	70.00	70.00	60.18	75.60	76.30	0.9
249	001530	109	pcbb	1	70.00	70.00	70.00	101.50	100.90	115.24	14.2
250	021130	125	pcbb	1	40.00	40.00	40.00	28.00	39.24	51.52	31.3
251	021130	123	pcbb	1	40.00	40.00	40.00	28.00	39.00	51.52	32.1
252	023320	125	pcbb	1	40.00	40.00	40.00	28.00	44.80	51.52	15.0
253	027940	106	pcbb	1	48.00	48.00	48.00	27.00	49.60	50.83	02.5
254	027940	111	pcbb	1	48.00	48.00	48.00	60.18	73.70	76.30	03.5
255	027940	108	pcbb	1	48.00	48.00	48.00	82.00	87.30	95.87	09.8
256	027940	112	pcbb	1	48.00	48.00	48.00	85.49	94.20	99.20	05.3
257	027940	122	pcbb	1	48.00	48.00	48.00	99.83	109.70	113.51	03.5
258	027940	109	pcbb	1	48.00	48.00	48.00	101.50	92.70	115.24	24.3
259	030630	108	pcbb	1	44.00	44.00	44.00	82.00	95.70	95.87	0.2
260	030630	109	pcbb	1	44.00	44.00	44.00	101.50	102.20	115.24	12.8
261	009250	109	pcib	1	39.77	39.77	39.77	101.50	108.30	115.24	06.4
262	014690	108	pcib	1	37.00	37.00	37.00	82.00	92.60	95.87	03.5
263	014690	112	pcib	1	37.00	37.00	37.00	85.49	96.90	99.20	02.4
264	014690	109	pcib	1	37.00	37.00	37.00	101.50	106.00	115.24	08.7
265	019960	108	rcs	1	21.50	21.50	21.50	82.00	93.60	95.87	02.4
266	019960	109	rcs	1	21.50	21.50	21.50	101.50	112.10	115.24	02.8
267	009120	109	sb	1	50.00	50.00	50.00	101.50	113.30	115.24	01.7
268	012240	111	sb	1	75.00	75.00	75.00	60.18	72.80	76.30	04.8
269	012240	109	sb	1	75.00	75.00	75.00	101.50	98.60	115.24	16.9
270	014340	106	sb	1	55.00	55.00	55.00	27.00	50.10	50.83	01.4

Table 4.11 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
271	014340	111	sb	1	55.00	55.00	55.00	60.18	72.90	76.30	04.7
272	014340	108	sb	1	55.00	55.00	55.00	82.00	88.10	95.87	08.8
273	014340	112	sb	1	55.00	55.00	55.00	85.49	97.20	99.20	02.1
274	014340	122	sb	1	55.00	55.00	55.00	99.83	108.10	113.51	05.0
275	014340	109	sb	1	55.00	55.00	55.00	101.50	92.00	115.24	25.3
276	005210	109	sg	1	84.00	84.00	84.00	101.50	114.50	115.24	0.6
277	030030	108	spt	1	28.70	28.70	28.70	82.00	93.20	95.87	02.9
278	030030	112	spt	1	28.70	28.70	28.70	85.49	98.80	99.20	0.4
279	030030	109	spt	1	28.70	28.70	28.70	101.50	111.70	115.24	03.2
280	014310	102	stt	1	30.67	30.67	30.67	22.00	47.20	47.43	0.5
281	014310	106	stt	1	30.67	30.67	30.67	27.00	48.10	50.83	05.7
282	014310	125	stt	1	30.67	30.67	30.67	28.00	51.26	51.52	0.5
283	014310	111	stt	1	30.67	30.67	30.67	60.18	71.70	76.30	06.4
284	014310	116	stt	1	30.78	30.78	30.78	82.00	94.10	95.87	01.9
285	014310	108	stt	1	30.67	30.67	30.67	82.00	85.20	95.87	12.5
286	014310	112	stt	1	30.78	30.78	30.78	85.49	90.70	99.20	09.4
287	014310	122	stt	1	30.67	30.67	30.67	99.83	107.00	113.51	06.1
288	014310	109	stt	1	30.67	30.67	30.67	101.50	90.30	115.24	27.6
289	029560	101	stt	1	21.67	21.67	21.67	11.58	27.90	40.74	46.0
290	029560	102	stt	1	21.67	21.67	21.67	22.00	30.50	47.43	55.5
291	029560	106	stt	1	21.67	21.67	21.67	27.00	31.40	50.83	61.9
292	029560	123	stt	1	21.67	21.67	21.67	28.00	36.60	51.52	40.8
293	029560	125	stt	1	21.67	21.67	21.67	28.00	34.51	51.52	49.3
294	029560	103	stt	1	21.67	21.67	21.67	47.50	53.00	65.96	24.4
295	029560	107	stt	1	21.67	21.67	21.67	58.47	46.10	74.86	62.4
296	029560	111	stt	1	21.67	21.67	21.67	60.18	47.80	76.30	59.6
297	029560	104	stt	1	21.67	21.67	21.67	67.57	51.10	82.68	61.8
298	029560	124	stt	1	21.67	21.67	21.67	76.00	61.50	90.27	46.8
299	029560	116	stt	1	21.67	21.67	21.67	82.00	57.40	95.87	67.0
300	029560	108	stt	1	21.67	21.67	21.67	82.00	53.40	95.87	79.5

Table 4.11 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
301	029560	112	stt	1	21.67	21.67	21.67	85.49	56.10	99.20	76.8
302	029560	122	stt	1	18.00	18.00	18.00	99.83	92.20	113.51	23.1
303	029560	109	stt	1	21.67	21.67	21.67	101.50	62.30	115.24	85.0
304	029560	113	stt	1	21.67	21.67	21.67	102.90	85.20	116.70	37.0
305	029560	119	stt	1	21.67	21.67	21.67	117.36	94.40	132.31	40.2

Table 4.12 The list of bridges that are overestimated by route independent model at 90% confidence level for trucks with $10 \leq L \leq 120$ ft.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
1	013080	103	cpcbb	3	40.00	24.00	88.00	47.50	59.50	61.92	04.1
2	013080	107	cpcbb	3	40.00	24.00	88.00	58.47	65.40	70.55	07.9
3	013080	111	cpcbb	3	40.00	24.00	88.00	60.18	59.70	71.95	20.5
4	013080	124	cpcbb	3	40.00	24.00	88.00	76.00	78.10	85.53	09.5
5	013080	116	cpcbb	3	40.00	24.00	88.00	82.00	86.00	90.98	05.8
6	013080	108	cpcbb	3	40.00	24.00	88.00	82.00	84.00	90.98	08.3
7	013080	112	cpcbb	3	40.00	24.00	88.00	85.49	87.60	94.23	07.6
8	013080	122	cpcbb	3	40.00	24.00	88.00	99.83	106.20	108.19	01.9
9	013080	109	cpcbb	3	40.00	24.00	88.00	101.50	87.10	109.88	26.2
10	013080	113	cpcbb	3	40.00	24.00	88.00	102.90	107.10	111.30	03.9
11	013080	119	cpcbb	3	40.00	24.00	88.00	117.36	116.80	126.56	08.4
12	021130	124	cpcbb	2	40.00	40.00	80.00	76.00	50.20	85.53	70.4
13	021130	122	cpcbb	2	40.00	40.00	80.00	99.83	69.30	108.19	56.1
14	026520	101	cpcbb	3	48.50	47.75	144.00	11.58	31.10	37.58	20.8
15	026520	102	cpcbb	3	48.50	47.75	144.00	22.00	33.40	44.02	31.8
16	026520	106	cpcbb	3	48.50	47.75	144.00	27.00	34.60	47.29	36.7
17	026520	125	cpcbb	3	48.50	47.75	144.00	28.00	43.88	47.95	09.3
18	026520	123	cpcbb	3	48.50	47.75	144.00	28.00	39.00	47.95	23.0
19	026520	103	cpcbb	3	48.50	47.75	144.00	47.50	56.20	61.92	10.2
20	026520	107	cpcbb	3	48.50	47.75	144.00	58.47	59.70	70.55	18.2
21	026520	111	cpcbb	3	48.50	47.75	144.00	60.18	56.50	71.95	27.3
22	026520	104	cpcbb	3	48.50	47.75	144.00	67.57	62.80	78.15	24.4
23	026520	124	cpcbb	3	48.50	47.75	144.00	76.00	72.00	85.53	18.8
24	026520	116	cpcbb	3	48.50	47.75	144.00	82.00	70.20	90.98	29.6
25	026520	108	cpcbb	3	48.50	47.75	144.00	82.00	67.50	90.98	34.8
26	026520	112	cpcbb	3	48.50	47.75	144.00	85.49	74.40	94.23	26.7
27	026520	122	cpcbb	3	48.50	47.75	144.00	99.83	84.00	108.19	28.8
28	026520	109	cpcbb	3	48.50	47.75	144.00	101.50	73.90	109.88	48.7
29	026520	113	cpcbb	3	48.50	47.75	144.00	102.90	91.20	111.30	22.0
30	026520	119	cpcbb	3	48.50	47.75	144.00	117.36	111.40	126.56	13.6

Table 4.12 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
31	027150	107	cpcbb	3	44.00	44.00	132.00	58.47	70.10	70.55	0.6
32	027150	104	cpcbb	3	44.00	44.00	132.00	67.57	75.40	78.15	03.6
33	027150	124	cpcbb	3	44.00	44.00	132.00	76.00	84.70	85.53	01.0
34	027150	116	cpcbb	3	44.00	44.00	132.00	82.00	84.70	90.98	07.4
35	027150	108	cpcbb	3	44.00	44.00	132.00	82.00	83.00	90.98	09.6
36	027150	112	cpcbb	3	44.00	44.00	132.00	85.49	92.60	94.23	01.8
37	027450	104	cpcbb	5	48.50	47.75	241.00	67.57	77.60	78.15	0.7
38	027450	116	cpcbb	5	48.50	47.75	241.00	82.00	88.50	90.98	02.8
39	027450	108	cpcbb	5	48.50	47.75	241.00	82.00	84.80	90.98	07.3
40	027450	112	cpcbb	5	48.50	47.75	241.00	85.49	93.80	94.23	0.5
41	027450	122	cpcbb	5	48.50	47.75	241.00	99.83	106.20	108.19	01.9
42	015930	109	cpcib	3	40.00	35.00	110.00	101.50	108.80	109.88	01.0
43	022770	111	cpcib	5	75.00	62.50	325.00	60.18	67.90	71.95	06.0
44	022770	108	cpcib	5	75.00	62.50	325.00	82.00	83.40	90.98	09.1
45	022770	112	cpcib	5	75.00	62.50	325.00	85.49	92.00	94.23	02.4
46	022770	122	cpcib	5	75.00	62.50	325.00	99.83	103.10	108.19	04.9
47	022770	109	cpcib	5	75.00	62.50	325.00	101.50	87.80	109.88	25.1
48	022770	113	cpcib	5	75.00	62.50	325.00	102.90	110.20	111.30	01.0
49	024835	106	cpcib	3	43.50	42.75	129.00	27.00	46.50	47.29	01.7
50	024835	108	cpcib	3	43.50	42.75	129.00	82.00	89.00	90.98	02.2
51	024835	109	cpcib	3	43.50	42.75	129.00	101.50	94.20	109.88	16.6
52	029940	109	cpcib	3	71.50	70.75	213.00	101.50	98.30	109.88	11.8
53	037930	125	cpcib	4	100.50	33.50	268.00	28.00	31.14	47.95	54.0
54	014750	102	crcg	3	63.00	47.00	157.00	22.00	42.90	44.02	02.6
55	014750	106	crcg	3	63.00	47.00	157.00	27.00	45.80	47.29	03.2
56	014750	107	crcg	3	63.00	47.00	157.00	58.47	68.10	70.55	03.6
57	014750	111	crcg	3	63.00	47.00	157.00	60.18	70.90	71.95	01.5
58	014750	104	crcg	3	63.00	47.00	157.00	67.57	74.80	78.15	04.5
59	014750	116	crcg	3	63.00	47.00	157.00	82.00	83.60	90.98	08.8
60	014750	108	crcg	3	63.00	47.00	157.00	82.00	79.40	90.98	14.6

Table 4.12 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
61	014750	112	crcg	3	63.00	47.00	157.00	85.49	82.10	94.23	14.8
62	014750	109	crcg	3	63.00	47.00	157.00	101.50	90.90	109.88	20.9
63	034280	109	crcg	3	56.00	43.00	142.00	101.50	104.40	109.88	05.2
64	004740	109	crcs	3	25.00	19.00	63.00	101.50	105.30	109.88	04.3
65	008230	125	crcs	3	32.00	24.00	80.00	28.00	47.90	47.95	0.1
66	008230	107	crcs	3	32.00	24.00	80.00	58.47	69.20	70.55	02.0
67	008230	104	crcs	3	32.00	24.00	80.00	67.57	73.90	78.15	05.7
68	008230	116	crcs	3	32.00	24.00	80.00	82.00	84.80	90.98	07.3
69	008230	108	crcs	3	32.00	24.00	80.00	82.00	80.50	90.98	13.0
70	008230	112	crcs	3	32.00	24.00	80.00	85.49	83.80	94.23	12.4
71	008230	109	crcs	3	32.00	24.00	80.00	101.50	96.80	109.88	13.5
72	013100	109	crcs	3	30.00	22.50	75.00	101.50	96.10	109.88	14.3
73	019937	101	crcs	3	29.00	21.75	72.50	11.58	21.80	37.58	72.4
74	019937	102	crcs	3	29.00	21.75	72.50	22.00	25.70	44.02	71.3
75	019937	106	crcs	3	29.00	21.75	72.50	27.00	26.00	47.29	81.9
76	019937	123	crcs	3	29.00	21.75	72.50	28.00	33.00	47.95	45.3
77	019937	125	crcs	3	29.00	21.75	72.50	28.00	27.25	47.95	76.0
78	019937	103	crcs	3	29.00	21.75	72.50	47.50	48.30	61.92	28.2
79	019937	107	crcs	3	29.00	21.75	72.50	58.47	36.70	70.55	92.2
80	019937	111	crcs	3	29.00	21.75	72.50	60.18	45.40	71.95	58.5
81	019937	104	crcs	3	29.00	21.75	72.50	67.57	42.10	78.15	85.6
82	019937	124	crcs	3	29.00	21.75	72.50	76.00	52.70	85.53	62.3
83	019937	108	crcs	3	29.00	21.75	72.50	82.00	68.70	90.98	32.4
84	019937	116	crcs	3	29.00	21.75	72.50	82.00	46.80	90.98	94.4
85	019937	112	crcs	3	29.00	21.75	72.50	85.49	44.70	94.23	110.8
86	019937	122	crcs	3	29.00	21.75	72.50	99.83	79.60	108.19	35.9
87	019937	109	crcs	3	29.00	21.75	72.50	101.50	65.60	109.88	67.5
88	019937	113	crcs	3	29.00	21.75	72.50	102.90	70.90	111.30	57.0
89	019937	119	crcs	3	29.00	21.75	72.50	117.36	94.30	126.56	34.2
90	021600	109	crcs	3	45.50	32.50	110.50	101.50	99.20	109.88	10.8

Table 4.12 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
91	028370	109	crcs	3	36.00	27.00	90.00	101.50	98.80	109.88	11.2
92	037960	109	crcs	3	35.00	25.00	85.00	101.50	104.70	109.88	04.9
93	038320	106	crcs	3	36.00	27.00	90.00	27.00	46.80	47.29	01.0
94	038320	125	crcs	3	36.00	27.00	90.00	28.00	47.43	47.95	01.1
95	038320	112	crcs	3	36.00	27.00	90.00	85.49	88.10	94.23	07.0
96	038320	109	crcs	3	36.00	27.00	90.00	101.50	98.00	109.88	12.1
97	039600	104	crcs	3	47.33	36.33	119.99	67.57	78.10	78.15	0.1
98	039600	108	crcs	3	47.33	36.33	119.99	82.00	84.50	90.98	07.7
99	039800	125	crcs	3	20.00	16.00	52.00	28.00	42.91	47.95	11.7
100	039800	104	crcs	3	20.00	16.00	52.00	67.57	76.60	78.15	02.0
101	039800	116	crcs	3	20.00	16.00	52.00	82.00	87.50	90.98	04.0
102	039800	108	crcs	3	20.00	16.00	52.00	82.00	81.30	90.98	11.9
103	039800	112	crcs	3	20.00	16.00	52.00	85.49	89.90	94.23	04.8
104	039800	122	crcs	3	20.00	16.00	52.00	99.83	97.20	108.19	11.3
105	039800	109	crcs	3	20.00	16.00	52.00	101.50	82.60	109.88	33.0
106	039800	113	crcs	3	20.00	16.00	52.00	102.90	98.70	111.30	12.8
107	039970	108	crcs	3	28.00	21.00	70.00	82.00	87.00	90.98	04.6
108	039970	122	crcs	3	28.00	21.00	70.00	99.83	102.80	108.19	05.2
109	039970	109	crcs	3	28.00	21.00	70.00	101.50	89.60	109.88	22.6
110	041340	109	crcs	3	41.50	32.00	105.50	101.50	100.90	109.88	08.9
111	049330	109	crcs	3	40.00	30.00	100.00	101.50	98.30	109.88	11.8
112	000970	109	csb	2	67.50	67.50	135.00	101.50	107.40	109.88	02.3
113	015450	109	csb	3	85.00	68.00	221.00	101.50	107.20	109.88	02.5
114	022600	102	csb	2	70.00	70.00	140.00	22.00	42.60	44.02	03.3
115	022600	106	csb	2	70.00	70.00	140.00	27.00	43.30	47.29	09.2
116	022600	123	csb	2	70.00	70.00	140.00	28.00	46.60	47.95	02.9
117	022600	125	csb	2	70.00	70.00	140.00	28.00	44.69	47.95	07.3
118	022600	103	csb	2	70.00	70.00	140.00	47.50	59.30	61.92	04.4
119	022600	107	csb	2	70.00	70.00	140.00	58.47	68.40	70.55	03.1
120	022600	111	csb	2	70.00	70.00	140.00	60.18	59.00	71.95	22.0

Table 4.12 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
121	022600	124	csb	2	70.00	70.00	140.00	76.00	84.60	85.53	01.1
122	022600	116	csb	2	70.00	70.00	140.00	82.00	88.50	90.98	02.8
123	022600	108	csb	2	70.00	70.00	140.00	82.00	74.30	90.98	22.5
124	022600	112	csb	2	70.00	70.00	140.00	85.49	85.20	94.23	10.6
125	022600	122	csb	2	70.00	70.00	140.00	99.83	91.00	108.19	18.9
126	022600	109	csb	2	70.00	70.00	140.00	101.50	78.10	109.88	40.7
127	022600	113	csb	2	70.00	70.00	140.00	102.90	100.60	111.30	10.6
128	022600	119	csb	2	70.00	70.00	140.00	117.36	115.60	126.56	09.5
129	038180	108	csb	3	62.00	37.00	136.00	82.00	87.70	90.98	03.7
130	038180	122	csb	3	62.00	37.00	136.00	99.83	108.10	108.19	0.1
131	038180	109	csb	3	62.00	37.00	136.00	101.50	109.10	109.88	0.7
132	038470	108	csb	3	60.00	49.00	158.00	82.00	88.00	90.98	03.4
133	038470	109	csb	3	60.00	49.00	158.00	101.50	96.50	109.88	13.9
134	043400	109	csb	5	60.00	50.00	280.00	101.50	109.60	109.88	0.3
135	044090	109	csb	3	72.00	60.00	192.00	101.50	104.20	109.88	05.4
136	049050	108	csb	3	53.00	44.50	142.00	82.00	81.50	90.98	11.6
137	049050	112	csb	3	53.00	44.50	142.00	85.49	88.90	94.23	06.0
138	049050	122	csb	3	53.00	44.50	142.00	99.83	107.80	108.19	0.4
139	049050	109	csb	3	53.00	44.50	142.00	101.50	90.80	109.88	21.0
140	050870	109	csb	3	66.00	55.00	176.00	101.50	100.40	109.88	09.4
141	050320	111	csg	6	111.00	88.00	620.00	60.18	71.50	71.95	0.6
142	050320	108	csg	6	111.00	88.00	620.00	82.00	89.30	90.98	01.9
143	050320	109	csg	6	111.00	88.00	620.00	101.50	104.40	109.88	05.2
144	041870	109	kcsb	3	83.50	69.75	223.00	101.50	109.10	109.88	0.7
145	042470	111	kcsb	4	74.90	40.00	243.00	60.18	68.40	71.95	05.2
146	042470	108	kcsb	4	74.90	40.00	243.00	82.00	89.60	90.98	01.5
147	042470	109	kcsb	4	74.90	40.00	243.00	101.50	98.50	109.88	11.6
148	050440	111	kcsb	2	74.00	74.00	148.00	60.18	70.50	71.95	02.1
149	050440	109	kcsb	2	74.00	74.00	148.00	101.50	99.80	109.88	10.1
150	034290	109	kcsg	3	89.00	32.00	161.00	101.50	108.00	109.88	01.7

Table 4.12 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
151	036030	111	ksb	1	80.25	80.25	80.25	60.18	68.00	71.95	05.8
152	036030	108	ksb	1	80.25	80.25	80.25	82.00	90.00	90.98	01.1
153	036030	109	ksb	1	80.25	80.25	80.25	101.50	93.20	109.88	17.9
154	001530	109	pcbb	1	70.00	70.00	70.00	101.50	100.90	109.88	08.9
155	021130	125	pcbb	1	40.00	40.00	40.00	28.00	39.24	47.95	22.2
156	021130	123	pcbb	1	40.00	40.00	40.00	28.00	39.00	47.95	23.0
157	023320	125	pcbb	1	40.00	40.00	40.00	28.00	44.80	47.95	07.0
158	027940	108	pcbb	1	48.00	48.00	48.00	82.00	87.30	90.98	04.2
159	027940	112	pcbb	1	48.00	48.00	48.00	85.49	94.20	94.23	0.0
160	027940	109	pcbb	1	48.00	48.00	48.00	101.50	92.70	109.88	18.5
161	030630	109	pcbb	1	44.00	44.00	44.00	101.50	102.20	109.88	07.5
162	009250	109	pcib	1	39.77	39.77	39.77	101.50	108.30	109.88	01.5
163	014690	109	pcib	1	37.00	37.00	37.00	101.50	106.00	109.88	03.7
164	012240	109	sb	1	75.00	75.00	75.00	101.50	98.60	109.88	11.4
165	014340	108	sb	1	55.00	55.00	55.00	82.00	88.10	90.98	03.3
166	014340	122	sb	1	55.00	55.00	55.00	99.83	108.10	108.19	0.1
167	014340	109	sb	1	55.00	55.00	55.00	101.50	92.00	109.88	19.4
168	014310	111	stt	1	30.67	30.67	30.67	60.18	71.70	71.95	0.4
169	014310	108	stt	1	30.67	30.67	30.67	82.00	85.20	90.98	06.8
170	014310	112	stt	1	30.78	30.78	30.78	85.49	90.70	94.23	03.9
171	014310	122	stt	1	30.67	30.67	30.67	99.83	107.00	108.19	01.1
172	014310	109	stt	1	30.67	30.67	30.67	101.50	90.30	109.88	21.7
173	029560	101	stt	1	21.67	21.67	21.67	11.58	27.90	37.58	34.7
174	029560	102	stt	1	21.67	21.67	21.67	22.00	30.50	44.02	44.3
175	029560	106	stt	1	21.67	21.67	21.67	27.00	31.40	47.29	50.6
176	029560	123	stt	1	21.67	21.67	21.67	28.00	36.60	47.95	31.0
177	029560	125	stt	1	21.67	21.67	21.67	28.00	34.51	47.95	39.0
178	029560	103	stt	1	21.67	21.67	21.67	47.50	53.00	61.92	16.8
179	029560	107	stt	1	21.67	21.67	21.67	58.47	46.10	70.55	53.0
180	029560	111	stt	1	21.67	21.67	21.67	60.18	47.80	71.95	50.5

Table 4.12 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
181	029560	104	stt	1	21.67	21.67	21.67	67.57	51.10	78.15	52.9
182	029560	124	stt	1	21.67	21.67	21.67	76.00	61.50	85.53	39.1
183	029560	116	stt	1	21.67	21.67	21.67	82.00	57.40	90.98	58.5
184	029560	108	stt	1	21.67	21.67	21.67	82.00	53.40	90.98	70.4
185	029560	112	stt	1	21.67	21.67	21.67	85.49	56.10	94.23	68.0
186	029560	122	stt	1	18.00	18.00	18.00	99.83	92.20	108.19	17.3
187	029560	109	stt	1	21.67	21.67	21.67	101.50	62.30	109.88	76.4
188	029560	113	stt	1	21.67	21.67	21.67	102.90	85.20	111.30	30.6
189	029560	119	stt	1	21.67	21.67	21.67	117.36	94.40	126.56	34.1

Table 4.13 The list of bridges that are overestimated by the route independent model at 95% confidence level for trucks with $10 \leq L \leq 120$ ft.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
1	013080	111	cpcbb	3	40.0	24.00	88	60.18	59.7	65.73	10.1
2	013080	124	cpcbb	3	40.0	24.00	88	76.00	78.1	78.73	0.8
3	013080	109	cpcbb	3	40.0	24.00	88	101.50	87.1	102.16	17.2
4	013080	119	cpcbb	3	40.0	24.00	88	117.36	116.8	118.27	01.2
5	021130	124	cpcbb	2	40.0	40.00	80	76.00	50.2	78.73	56.8
6	021130	122	cpcbb	2	40.0	40.00	80	99.83	69.3	100.53	45.0
7	026520	101	cpcbb	3	48.5	47.75	144	11.58	31.1	33.12	06.5
8	026520	102	cpcbb	3	48.5	47.75	144	22.00	33.4	39.18	17.3
9	026520	106	cpcbb	3	48.5	47.75	144	27.00	34.6	42.27	22.1
10	026520	123	cpcbb	3	48.5	47.75	144	28.00	39.0	42.90	10.0
11	026520	107	cpcbb	3	48.5	47.75	144	58.47	59.7	64.40	07.8
12	026520	111	cpcbb	3	48.5	47.75	144	60.18	56.5	65.73	16.3
13	026520	104	cpcbb	3	48.5	47.75	144	67.57	62.8	71.66	14.1
14	026520	124	cpcbb	3	48.5	47.75	144	76.00	72.0	78.73	09.3
15	026520	116	cpcbb	3	48.5	47.75	144	82.00	70.2	83.97	19.6
16	026520	108	cpcbb	3	48.5	47.75	144	82.00	67.5	83.97	24.4
17	026520	112	cpcbb	3	48.5	47.75	144	85.49	74.4	87.10	17.0
18	026520	122	cpcbb	3	48.5	47.75	144	99.83	84.0	100.53	19.6
19	026520	109	cpcbb	3	48.5	47.75	144	101.50	73.9	102.16	38.2
20	026520	113	cpcbb	3	48.5	47.75	144	102.90	91.2	103.53	13.5
21	026520	119	cpcbb	3	48.5	47.75	144	117.36	111.4	118.27	06.1
22	027150	108	cpcbb	3	44.0	44.00	132	82.00	83.0	83.97	01.1
23	022770	108	cpcib	5	75.0	62.50	325	82.0	83.40	83.97	0.6
24	022770	109	cpcib	5	75.0	62.50	325	101.5	87.80	102.16	16.3
25	024835	109	cpcib	3	43.5	42.75	129	101.5	94.20	102.16	08.4

Table 4.13 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
26	029940	109	cpcib	3	71.5	70.75	213	101.5	98.30	102.16	03.9
27	037930	125	cpcib	4	100.5	33.50	268	28.0	31.14	42.90	37.7
28	014750	116	crcg	3	63	47	157	82.00	83.6	83.97	0.4
29	014750	108	crcg	3	63	47	157	82.00	79.4	83.97	05.7
30	014750	112	crcg	3	63	47	157	85.49	82.1	87.10	06.0
31	014750	109	crcg	3	63	47	157	101.50	90.9	102.16	12.3
32	008230	108	crcs	3	32	24.00	80.0	82.00	80.50	83.97	04.3
33	008230	112	crcs	3	32	24.00	80.0	85.49	83.80	87.10	03.9
34	008230	109	crcs	3	32	24.00	80.0	101.50	96.80	102.16	05.5
35	013100	109	crcs	3	30	22.50	75.0	101.50	96.10	102.16	06.3
36	019937	101	crcs	3	29	21.75	72.5	11.58	21.80	33.12	51.9
37	019937	102	crcs	3	29	21.75	72.5	22.00	25.70	39.18	52.4
38	019937	106	crcs	3	29	21.75	72.5	27.00	26.00	42.27	62.5
39	019937	123	crcs	3	29	21.75	72.5	28.00	33.00	42.90	30.0
40	019937	125	crcs	3	29	21.75	72.5	28.00	27.25	42.90	57.4
41	019937	103	crcs	3	29	21.75	72.5	47.50	48.30	56.16	16.2
42	019937	107	crcs	3	29	21.75	72.5	58.47	36.70	64.40	75.4
43	019937	111	crcs	3	29	21.75	72.5	60.18	45.40	65.73	44.7
44	019937	104	crcs	3	29.0	21.75	72.5	67.57	42.1	71.66	70.2
45	019937	124	crcs	3	29.0	21.75	72.5	76.00	52.7	78.73	49.4
46	019937	108	crcs	3	29.0	21.75	72.5	82.00	68.7	83.97	22.2
47	019937	116	crcs	3	29.0	21.75	72.5	82.00	46.8	83.97	79.4
48	019937	112	crcs	3	29.0	21.75	72.5	85.49	44.7	87.10	94.8
49	019937	122	crcs	3	29.0	21.75	72.5	99.83	79.6	100.53	26.3
50	019937	109	crcs	3	29.0	21.75	72.5	101.50	65.6	102.16	55.7

Table 4.13 continued.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
51	019937	113	crcs	3	29.0	21.75	72.5	102.90	70.9	103.53	46.0
52	019937	119	crcs	3	29.0	21.75	72.5	117.36	94.3	118.27	25.4
53	021600	109	crcs	3	45.5	32.50	110.5	101.50	99.2	102.16	02.9
54	028370	109	crcs	3	36.0	27.00	90.0	101.50	98.8	102.16	03.4
55	038320	109	crcs	3	36.0	27.00	90.0	101.50	98.0	102.16	04.2
56	039800	108	crcs	3	20.0	16.00	52.0	82.00	81.3	83.97	03.2
57	039800	122	crcs	3	20.0	16.00	52.0	99.83	97.2	100.53	03.4
58	039800	109	crcs	3	20.0	16.00	52.0	101.50	82.6	102.16	23.6
59	039800	113	crcs	3	20.0	16.00	52.0	102.90	98.7	103.53	04.9
60	039970	109	crcs	3	28.0	21.00	70.0	101.50	89.6	102.16	14.0
61	041340	109	crcs	3	41.5	32.00	105.5	101.50	100.9	102.16	01.2
62	049330	109	crcs	3	40.0	30.00	100.0	101.50	98.3	102.16	03.9
63	022600	111	csb	2	70	70.0	140	60.18	59.0	65.73	11.4
64	022600	108	csb	2	70	70.0	140	82.00	74.3	83.97	13.0
65	022600	112	csb	2	70	70.0	140	85.49	85.2	87.10	02.2
66	022600	122	csb	2	70	70.0	140	99.83	91.0	100.53	10.4
67	022600	109	csb	2	70	70.0	140	101.50	78.1	102.16	30.8
68	022600	113	csb	2	70	70.0	140	102.90	100.6	103.53	02.9
69	022600	119	csb	2	70	70.0	140	117.36	115.6	118.27	02.3
70	038470	109	csb	3	60	49.0	158	101.50	96.5	102.16	05.8
71	049050	108	csb	3	53	44.5	142	82.00	81.5	83.97	03.0
72	049050	109	csb	3	53	44.5	142	101.50	90.8	102.16	12.5
73	050870	109	csb	3	66	55.0	176	101.50	100.4	102.16	01.7
74	042470	109	kcsb	4	74.9	40	243	101.5	98.5	102.164	03.7
75	050440	109	kcsb	2	74.0	74	148	101.5	99.8	102.164	02.3

Table 4.13 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
76	036030	109	ksb	1	80.25	80.25	80.25	101.5	93.2	102.16	09.6
77	001530	109	pcbb	1	70	70	70	101.5	100.90	102.16	01.2
78	021130	125	pcbb	1	40	40	40	28.0	39.24	42.90	09.3
79	021130	123	pcbb	1	40	40	40	28.0	39.00	42.90	10.0
80	027940	109	pcbb	1	48	48	48	101.5	92.70	102.16	10.2
81	012240	109	sb	1	75	75	75	101.5	98.6	102.16	03.6
82	014340	109	sb	1	55	55	55	101.5	92.0	102.16	11.0
83	014310	109	stt	1	30.67	30.67	30.67	101.50	90.30	102.16	13.1
84	029560	101	stt	1	21.67	21.67	21.67	11.58	27.90	33.12	18.7
85	029560	102	stt	1	21.67	21.67	21.67	22.00	30.50	39.18	28.4
86	029560	106	stt	1	21.67	21.67	21.67	27.00	31.40	42.27	34.6
87	029560	123	stt	1	21.67	21.67	21.67	28.00	36.60	42.90	17.2
88	029560	125	stt	1	21.67	21.67	21.67	28.00	34.50	42.90	24.3
89	029560	103	stt	1	21.67	21.67	21.67	47.50	53.00	56.16	05.9
90	029560	107	stt	1	21.67	21.67	21.67	58.47	46.10	64.40	39.6
91	029560	111	stt	1	21.67	21.67	21.67	60.18	47.80	65.73	37.5
92	029560	104	stt	1	21.67	21.67	21.67	67.57	51.10	71.66	40.2
93	029560	124	stt	1	21.67	21.67	21.67	76.00	61.50	78.73	28.0
94	029560	116	stt	1	21.67	21.67	21.67	82.00	57.40	83.97	46.2
95	029560	108	stt	1	21.67	21.67	21.67	82.00	53.40	83.97	57.2
96	029560	112	stt	1	21.67	21.67	21.67	85.49	56.10	87.10	55.2
97	029560	122	stt	1	18.00	18.00	18.00	99.83	92.20	100.53	09.0
98	029560	109	stt	1	21.67	21.67	21.67	101.50	62.30	102.16	63.9
99	029560	113	stt	1	21.67	21.67	21.67	102.90	85.20	103.53	21.5
100	029560	119	stt	1	21.67	21.67	21.67	117.36	94.40	118.27	25.7

Table 4.14 The list of bridges that are overestimated by the route independent model at 99% confidence level for trucks with $10 \leq L \leq 120$ ft.

Si. No.	*NBI No.*	*Truck No.*	*Group*	*No.of Spans*	*Max. Span*	*Min. Span*	*Bridge Length*	*Wheel Base*	*Allowable Load*	*Predicted Load*	*OER (%)*
1	013080	109	cpcbb	3	40.00	24.00	88	101.50	87.1	88.46	01.5
2	021130	124	cpcbb	2	40.00	40.00	80	76.00	50.2	66.77	33.0
3	021130	122	cpcbb	2	40.00	40.00	80	99.83	69.3	86.94	25.4
4	026520	116	cpcbb	3	48.50	47.75	144	82.00	70.2	71.60	01.9
5	026520	108	cpcbb	3	48.50	47.75	144	82.00	67.5	71.60	06.0
6	026520	112	cpcbb	3	48.50	47.75	144	85.49	74.4	74.48	0.1
7	026520	122	cpcbb	3	48.50	47.75	144	99.83	84.0	86.94	03.5
8	026520	109	cpcbb	3	48.50	47.75	144	101.50	73.9	88.46	19.7
9	022770	109	cpcib	5	75.0	62.5	325	101.5	87.80	88.46	0.7
10	037930	125	cpcib	4	100.5	33.5	268	28.0	31.14	34.20	09.8
11	019937	101	crcs	3	29	21.75	72.5	11.58	21.80	25.53	17.1
12	019937	102	crcs	3	29	21.75	72.5	22.00	25.70	30.88	20.1
13	019937	106	crcs	3	29	21.75	72.5	27.00	26.00	33.63	29.3
14	019937	123	crcs	3	29	21.75	72.5	28.00	33.00	34.20	03.6
15	019937	125	crcs	3	29	21.75	72.5	28.00	27.25	34.20	25.4
16	019937	107	crcs	3	29	21.75	72.5	58.47	36.70	53.62	46.1
17	019937	111	crcs	3	29	21.75	72.5	60.18	45.40	54.84	20.8
18	019937	104	crcs	3	29	21.75	72.5	67.57	42.10	60.26	43.1
19	019937	124	crcs	3	29	21.75	72.5	76.00	52.70	66.77	26.6
20	019937	108	crcs	3	29	21.75	72.5	82.00	68.70	71.60	04.2
21	019937	116	crcs	3	29	21.75	72.5	82.00	46.80	71.60	52.9
22	019937	112	crcs	3	29	21.75	72.5	85.49	44.70	74.48	66.6
23	019937	122	crcs	3	29	21.75	72.5	99.83	79.60	86.94	09.2
24	019937	109	crcs	3	29	21.75	72.5	101.50	65.60	88.46	34.8
25	019937	113	crcs	3	29	21.75	72.5	102.90	70.90	89.74	26.5

Table 4.14 continued.

Si. No.	NBI No.	Truck No.	Group	No.of Spans	Max. Span	Min. Span	Bridge Length	Wheel Base	Allowable Load	Predicted Load	OER (%)
26	019937	119	crcs	3	29	21.75	72.5	117.36	94.30	103.49	09.7
27	039800	109	crcs	3	20	16.00	52.0	101.50	82.60	88.46	07.0
28	022600	109	csb	2	70	70	140	101.5	78.1	88.46	13.2
29	029560	102	stt	1	21.67	21.67	21.67	22.00	30.5	30.88	01.2
30	029560	106	stt	1	21.67	21.67	21.67	27.00	31.4	33.63	07.1
31	029560	107	stt	1	21.67	21.67	21.67	58.47	46.1	53.62	16.3
32	029560	111	stt	1	21.67	21.67	21.67	60.18	47.8	54.84	14.7
33	029560	104	stt	1	21.67	21.67	21.67	67.57	51.1	60.26	17.9
34	029560	124	stt	1	21.67	21.67	21.67	76.00	61.5	66.77	08.5
35	029560	116	stt	1	21.67	21.67	21.67	82.00	57.4	71.60	24.7
36	029560	108	stt	1	21.67	21.67	21.67	82.00	53.4	71.60	34.0
37	029560	112	stt	1	21.67	21.67	21.67	85.49	56.1	74.48	32.7
38	029560	109	stt	1	21.67	21.67	21.67	101.50	62.3	88.46	41.9
39	029560	113	stt	1	21.67	21.67	21.67	102.90	85.2	89.74	05.3
40	029560	119	stt	1	21.67	21.67	21.67	117.36	94.4	103.49	09.6

Table 4.15 The percentage distribution of the points overestimated by the route independent model with OER and the maximum OER at 85%, 90%, 95%, and 99% confidence levels

Confidence Level (%)	% data below confidence level	OER interval (%)				Max. OER (%)
		0 – 10	10 – 30	30 – 50	> 50	
85	12.1	55	28	8	9	122
90	7.5	51	28	9	12	111
95	4.0	39	35	13	13	95
99	1.6	43	35	17	5	67

Table 4.16 Percentage distribution of data points, overestimated by the route independent model, for different ranges of HS truck capacity at 85%, 90%, 95%, and 99% confidence levels

HS truck cap. (ton)	*Percentage Frequencey*	*Percentage Confidence Level*			
		85%	*90%*	*95%*	*99%*
25 - 30	0.7	100.0	100.0	100.0	94.0
30 - 35	0.7	100.0	100.0	100.0	76.5
35 - 40	0.2	100.0	100.0	100.0	50.0
40 - 45	2.1	90.6	79.3	50.9	13.2
45 - 50	3.4	48.2	30.6	11.8	1.2
50 - 55	8.1	39.2	20.6	7.8	0.5
55 - 60	11.7	14.2	6.8	1.4	0.0
60 - 65	20.7	5.8	1.5	0.6	0.0
65 - 70	16.1	6.4	3.2	0.5	0.0
70 - 75	14.8	0.0	0.0	0.0	0.0
75 - 80	10.9	0.0	0.0	0.0	0.0
80 - 85	2.7	0.0	0.0	0.0	0.0
85 - 90	3.4	0.0	0.0	0.0	0.0
90 - 95	2.7	0.0	0.0	0.0	0.0
95 - 100	1.3	0.0	0.0	0.0	0.0
100 - 105	0.0	0.0	0.0	0.0	0.0
105 - 110	0.7	0.0	0.0	0.0	0.0

Table 4.17 The percentage distribution of the points, overestimated by the route dependent model, with OER and the maximum OER at 85%, 90%, 95%, and 99% confidence levels

Confidence Level (%)	*% data below confidence level*	*OER interval (%)*				*Max. OER (%)*
		0–10	10–20	20–30	>30	
85	13.8	74	16	5	5	83
90	8.5	73	18	4	5	74
95	4.2	70	18	8	4	60
99	1.1	76	10	10	4	36

Table 4.18 The degree of overestimation by the route independent formulae at different confidence levels when restricted to bridges of certain minimum HS truck capacities

Confidence Level (%)	*Minimum HS Truck Capacity (ton)*	*% data below*	*Max. OER (%)*
85	45	9	32
90	45	4.5	27
95	45	1.4	18
	40	2.5	39
99	45	0.08	1.0
	40	0.4	20

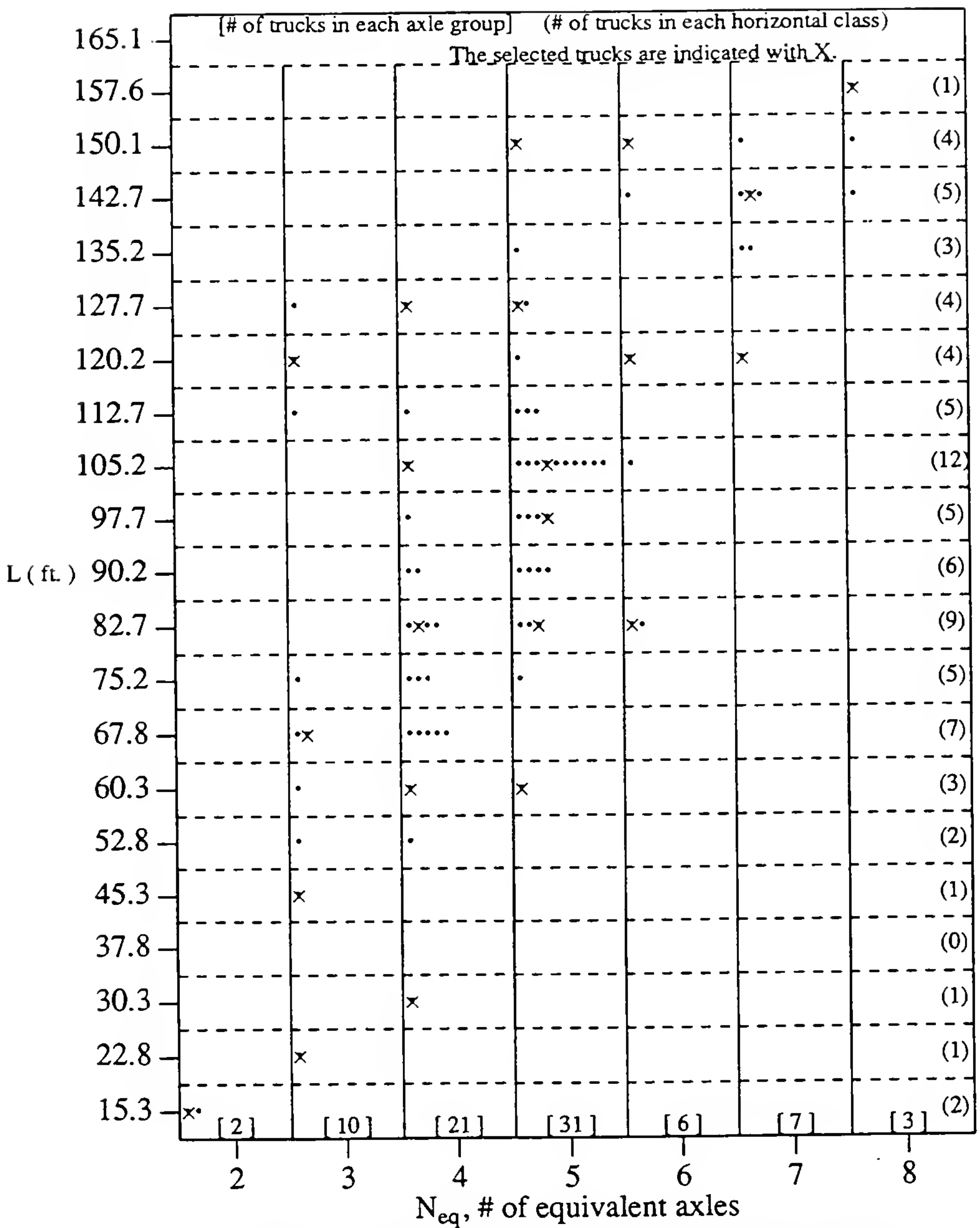


Figure 2.1 Truck population distribution with respect to number of equivalent axles, N_{eq} and wheel base, L.

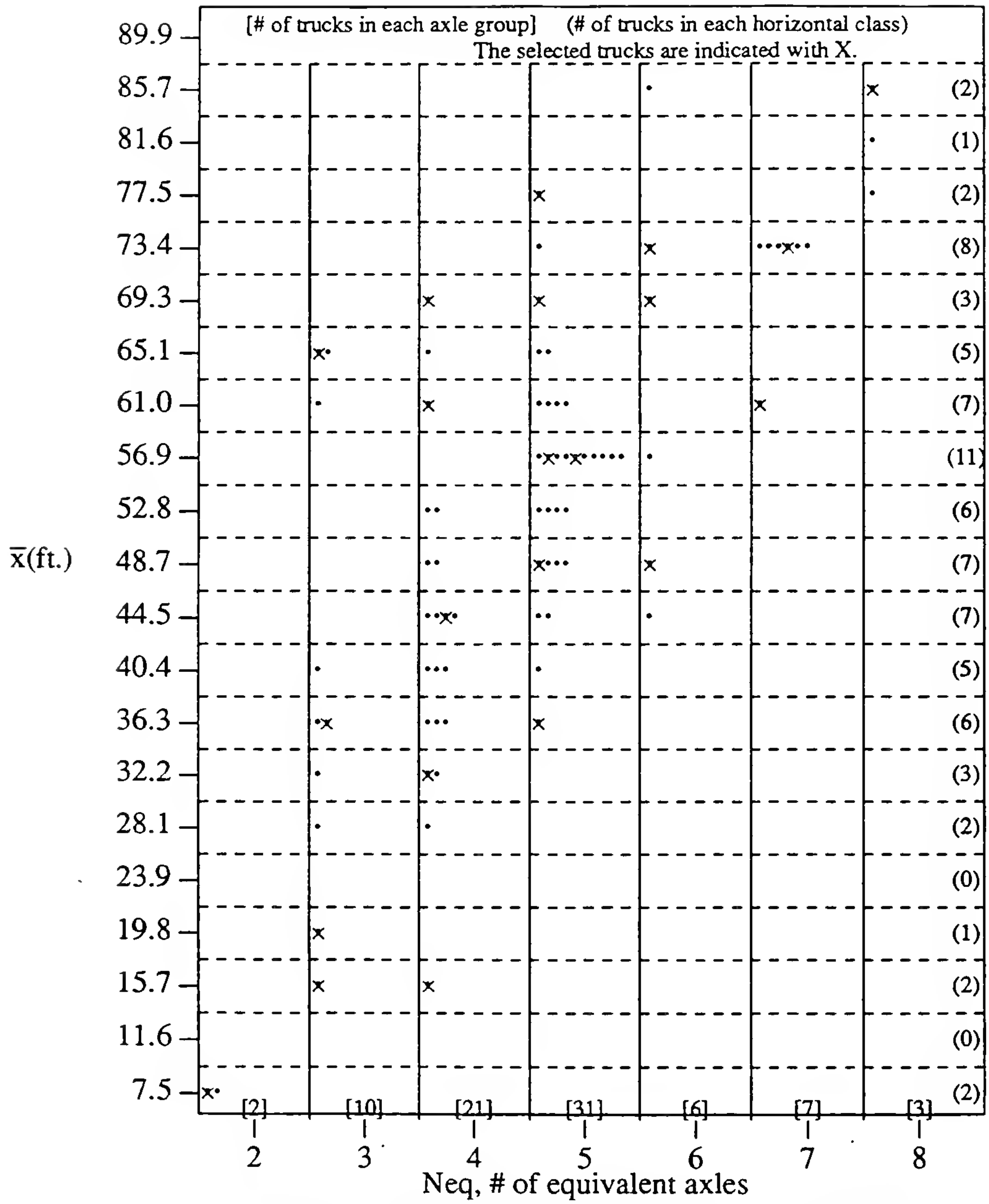


Figure 2.2 Truck population distribution with respect to number of equivalent axles, N_{eq} and distance of the resultant load from front axle, $\bar{x}$.

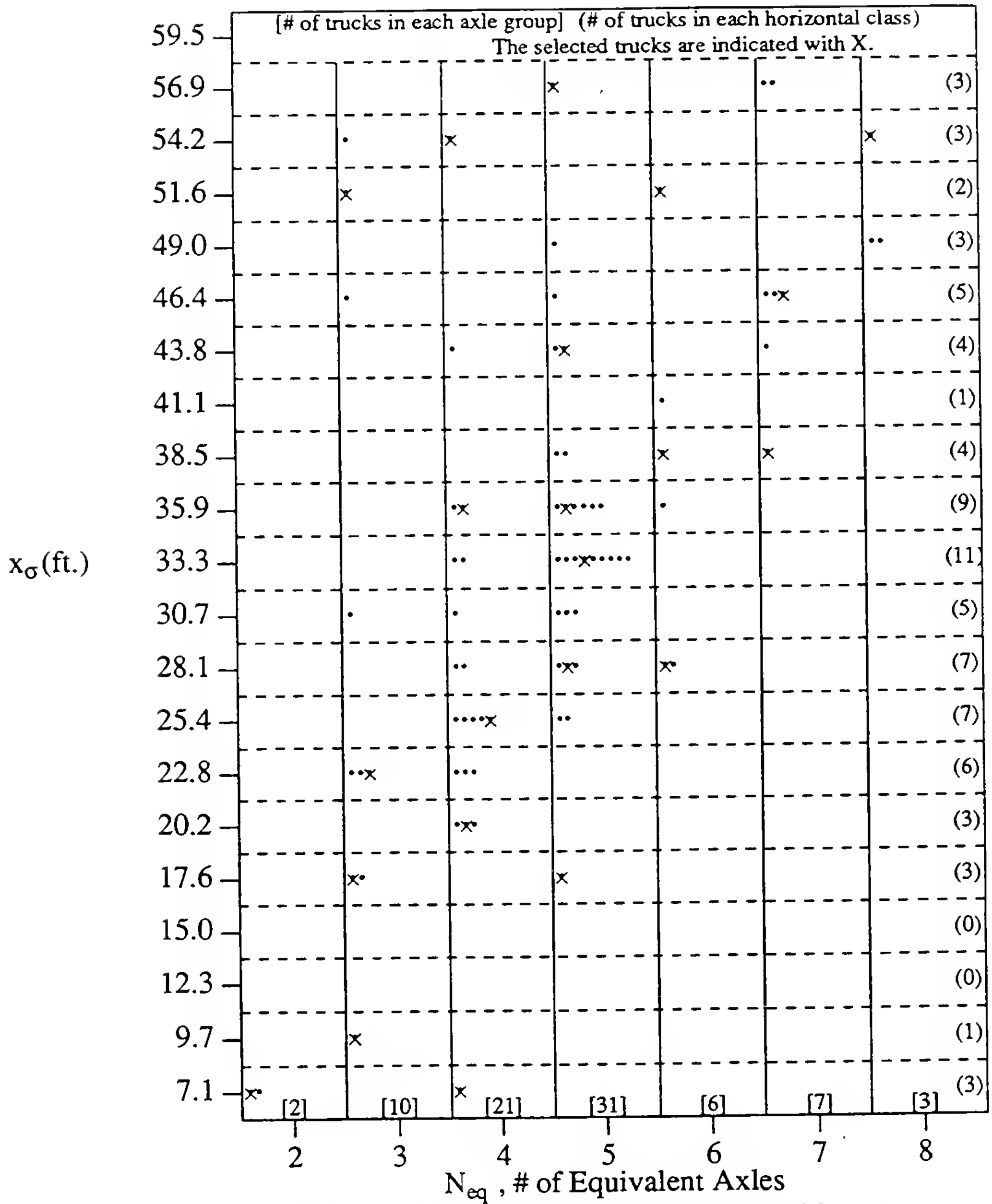


Figure 2.3 Truck population distribution with respect to number of equivalent axles, N_{eq} and standard deviation of truck load distribution, x_σ

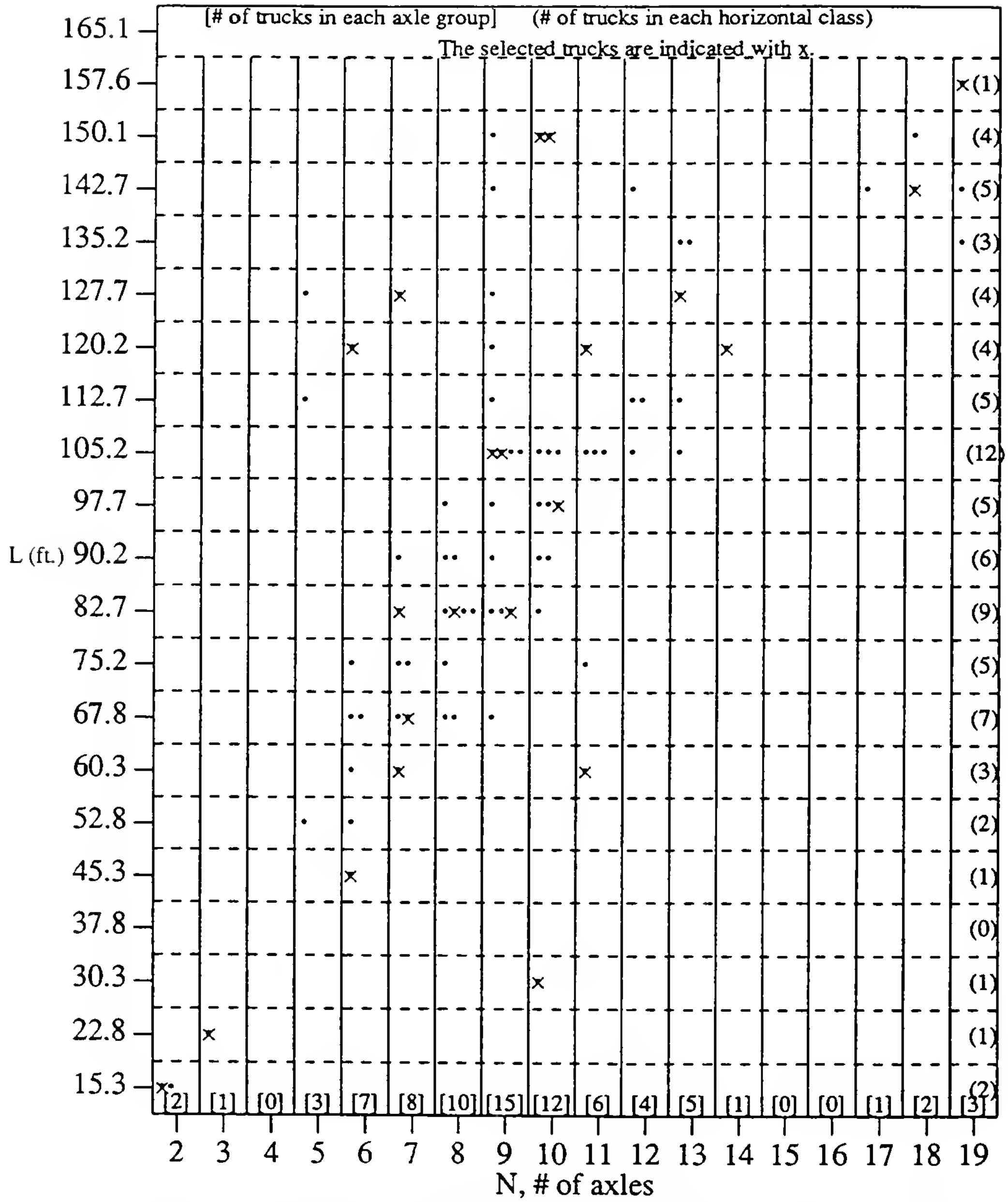


Figure 2.4 Truck population distribution with respect to number of axles, N, and wheel base, L.

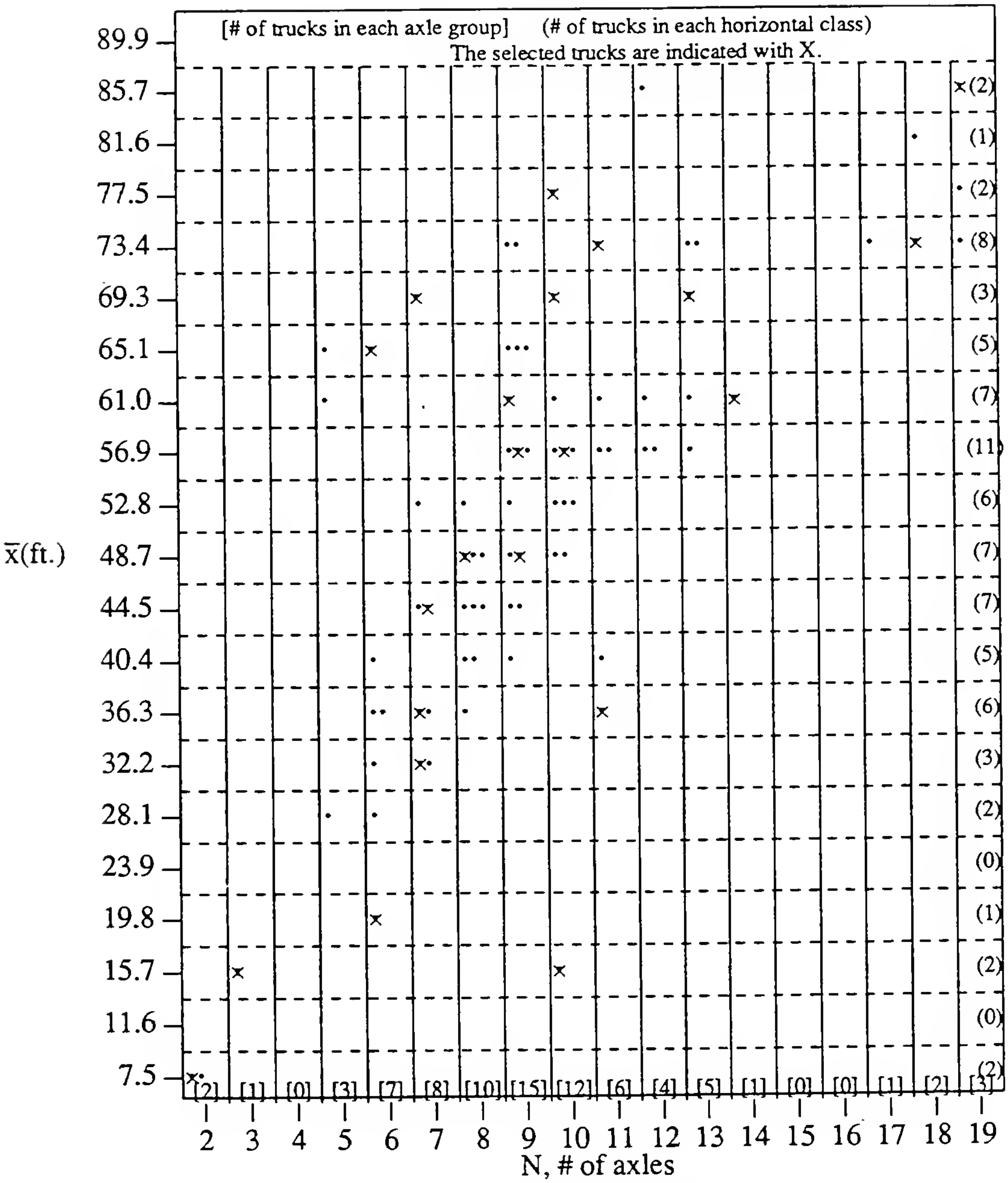


Figure 2.5 Truck population distribution with respect to number of axles, N, and distance of the resultant load from the front axle, $\bar{x}$.

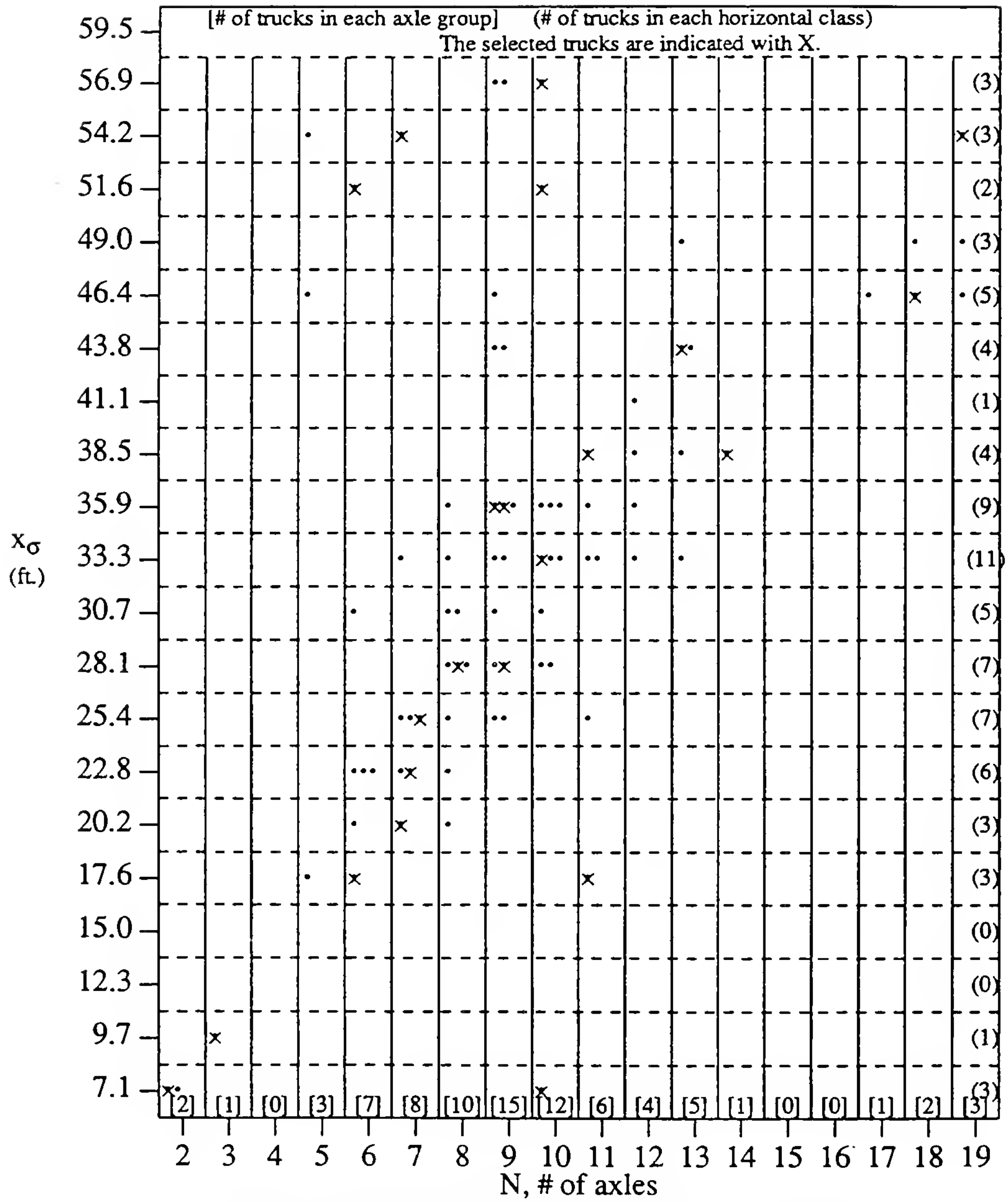


Figure 2.6 Truck population distribution with respect to number of axles, N, and standard deviation of the load distribution, x_σ.

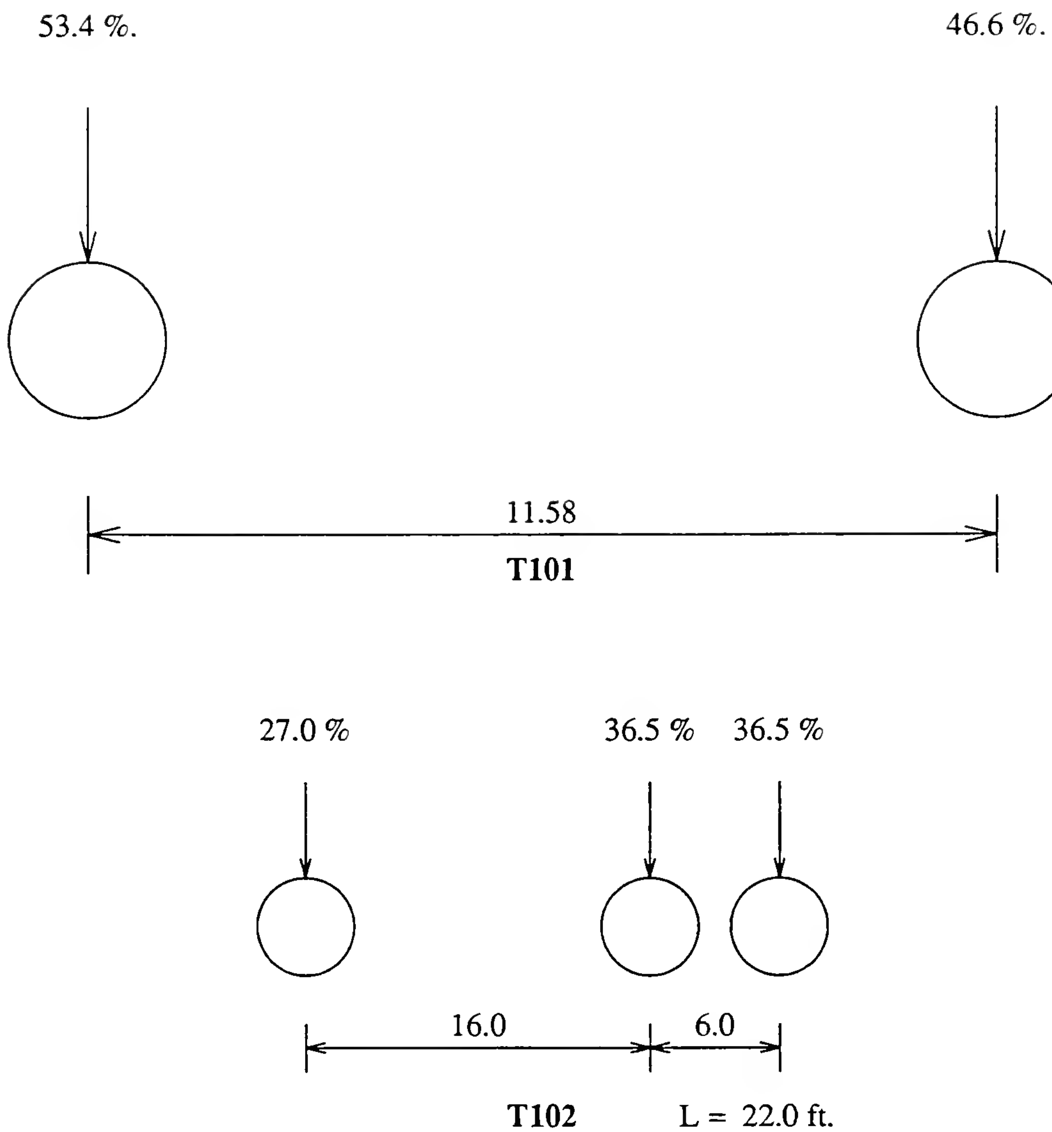
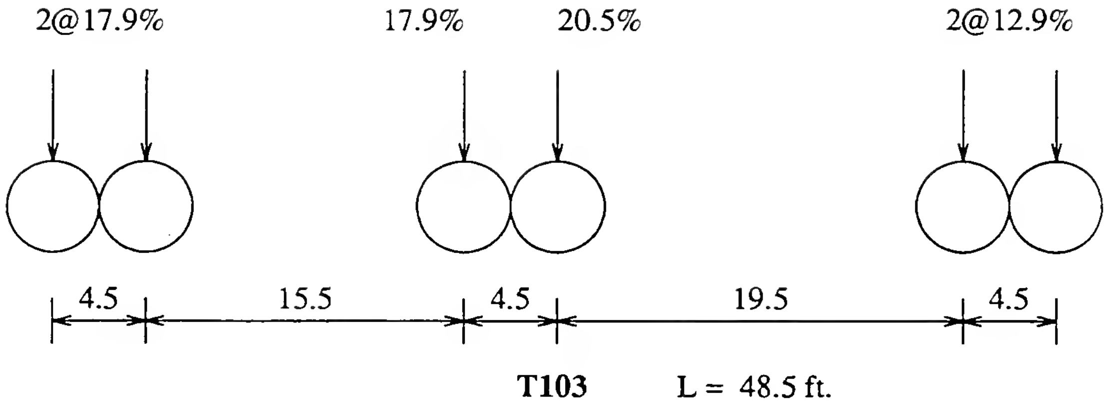


Figure 2.7 Overload trucks considered in the present study



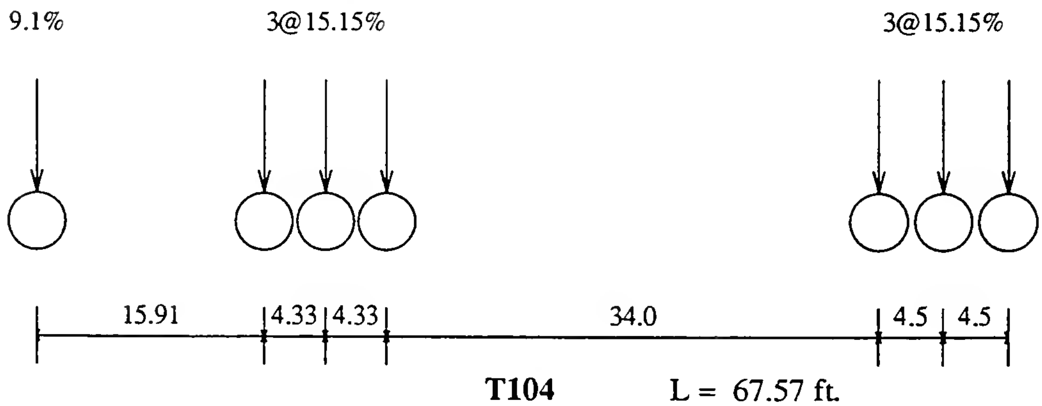
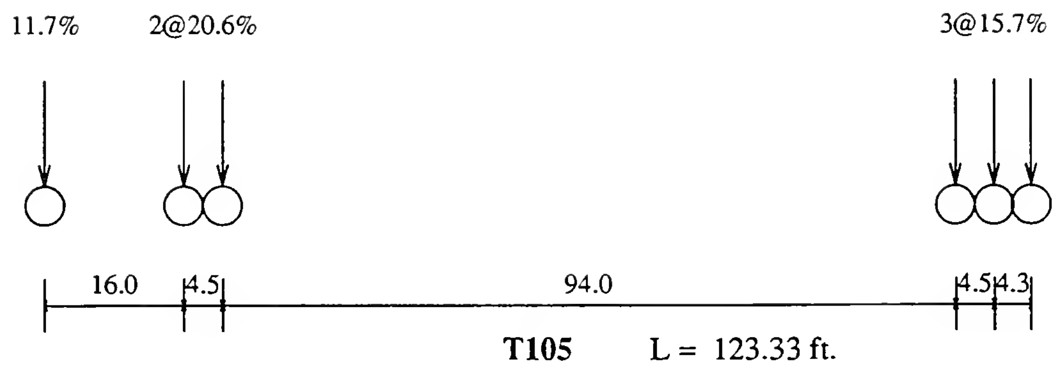
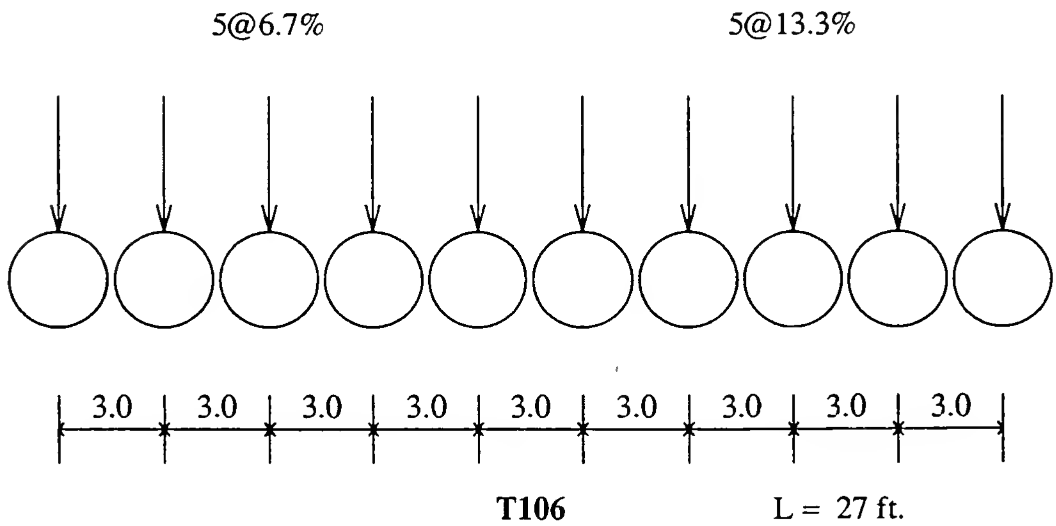


Figure 2.7 continued.





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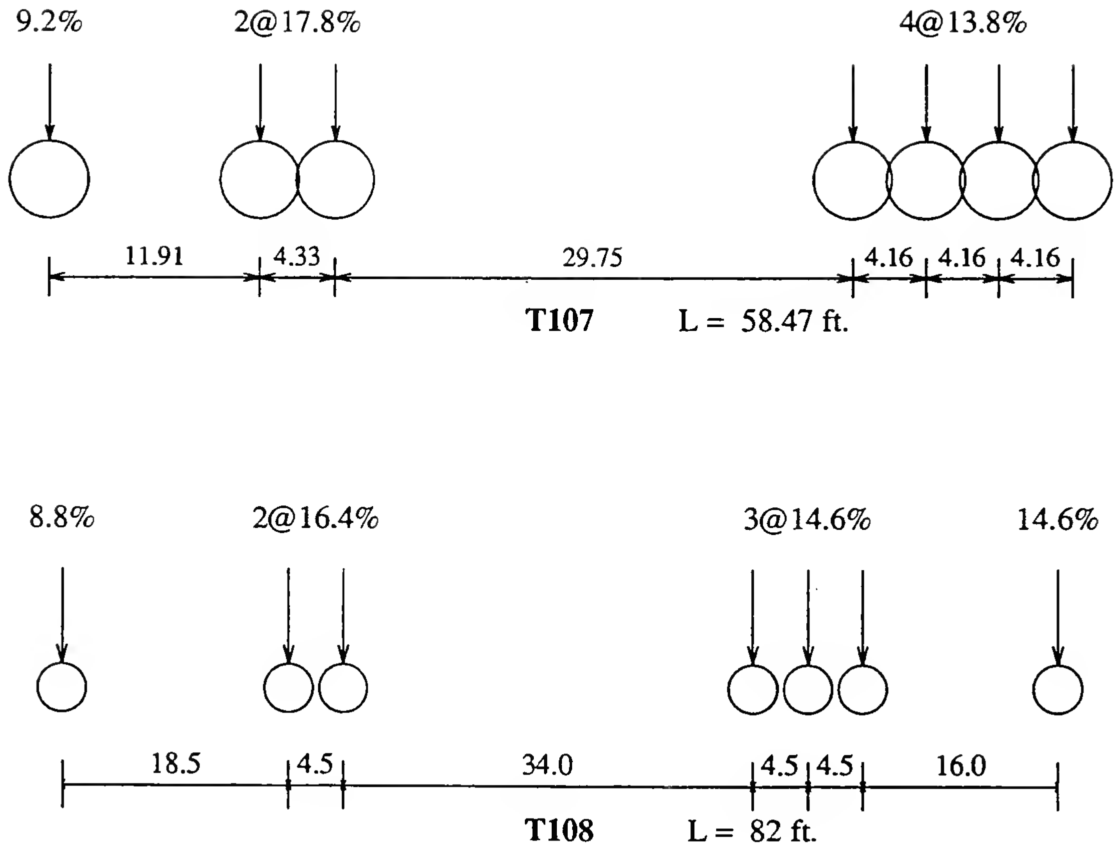

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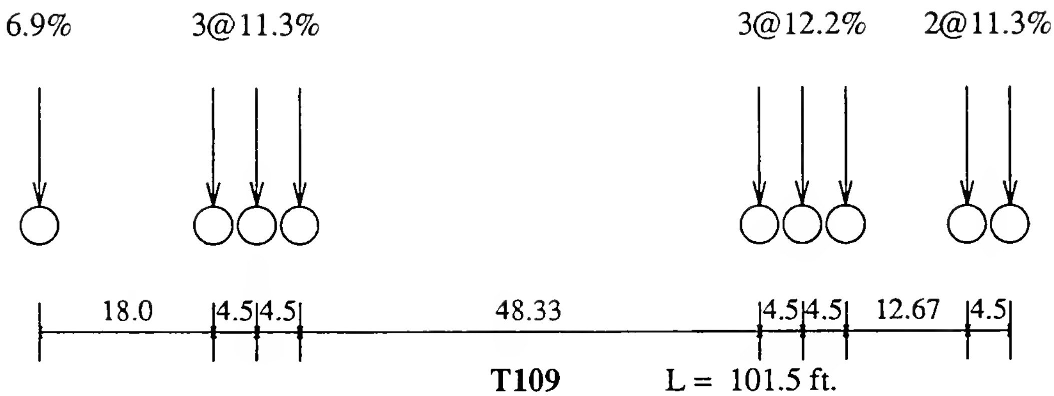

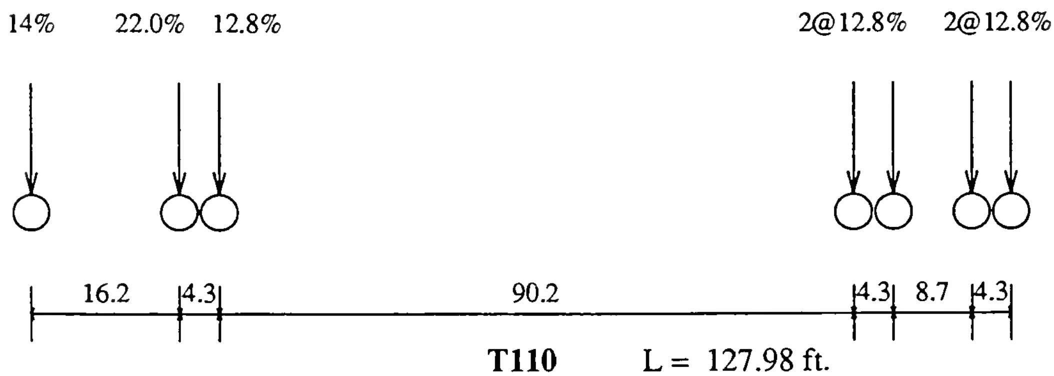

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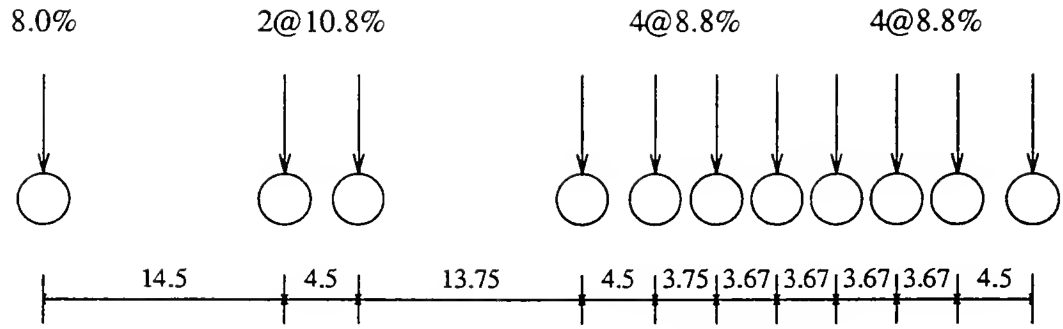
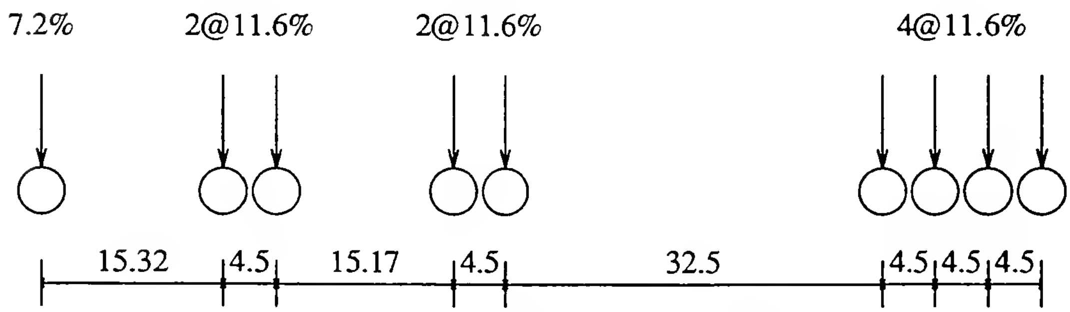


T111 L = 60.18 ft.



T112 L = 85.49 ft.

Figure 2.7 continued.

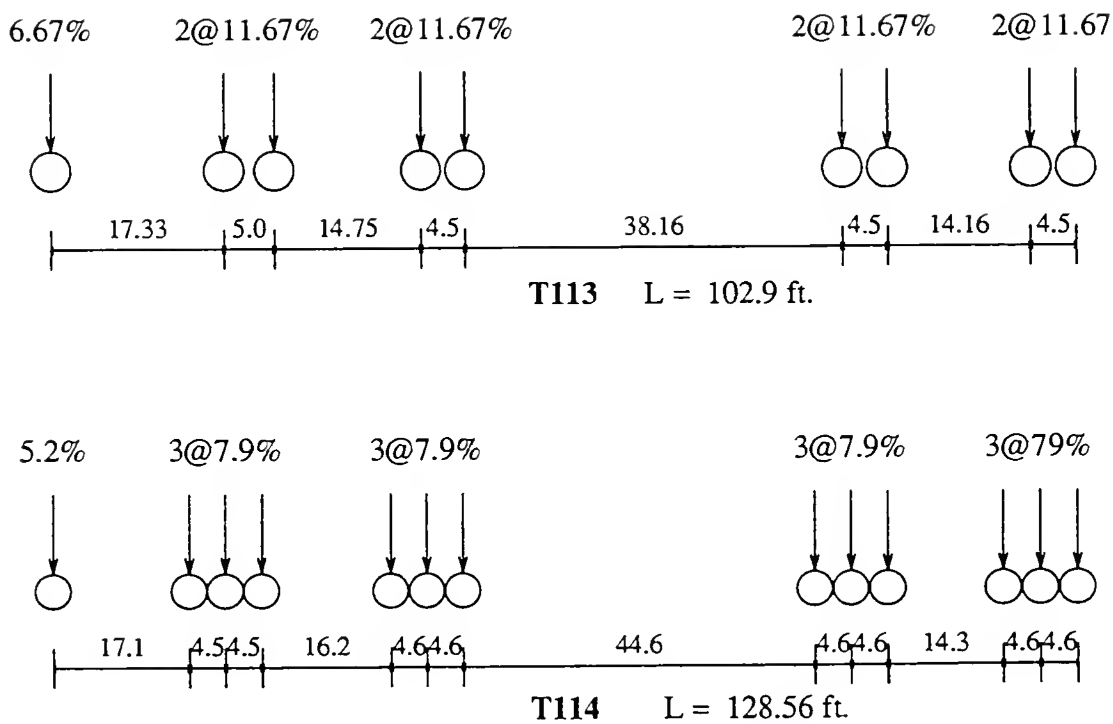
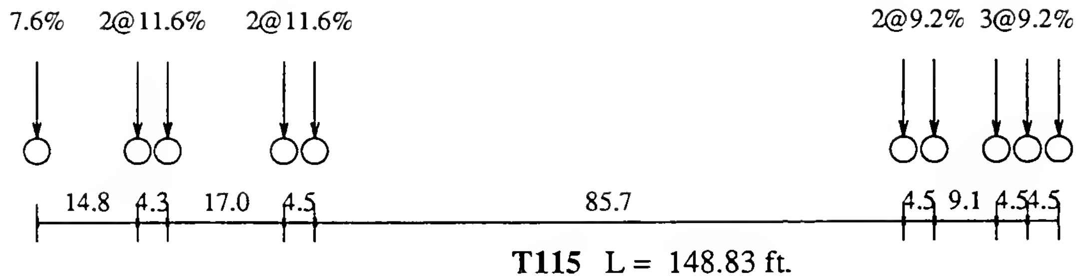


Figure 2.7 continued.



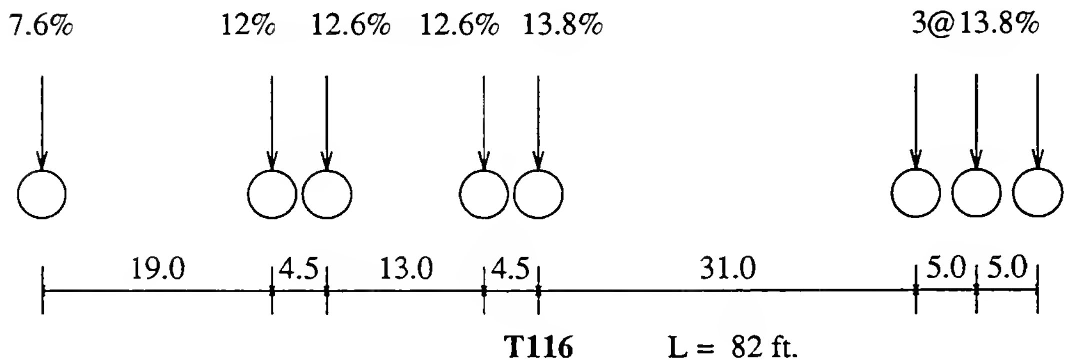
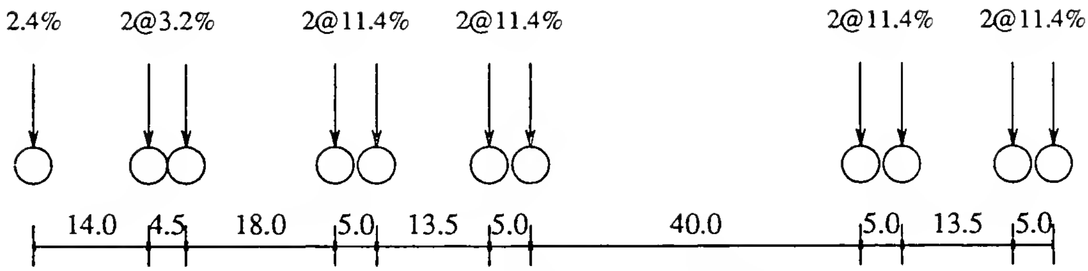
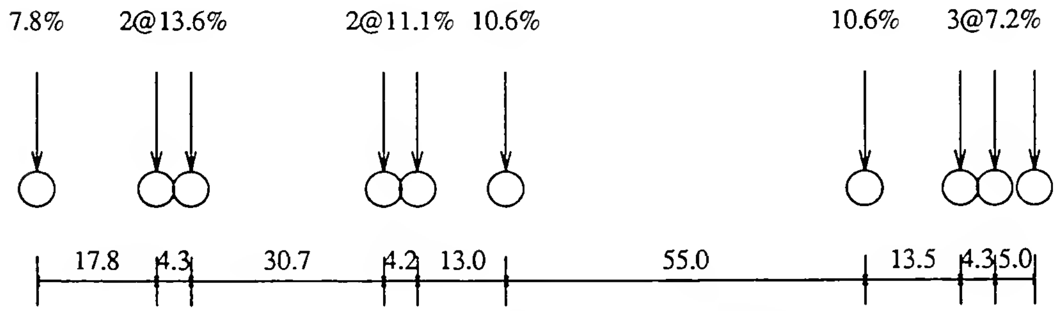


Figure 2.7 continued.

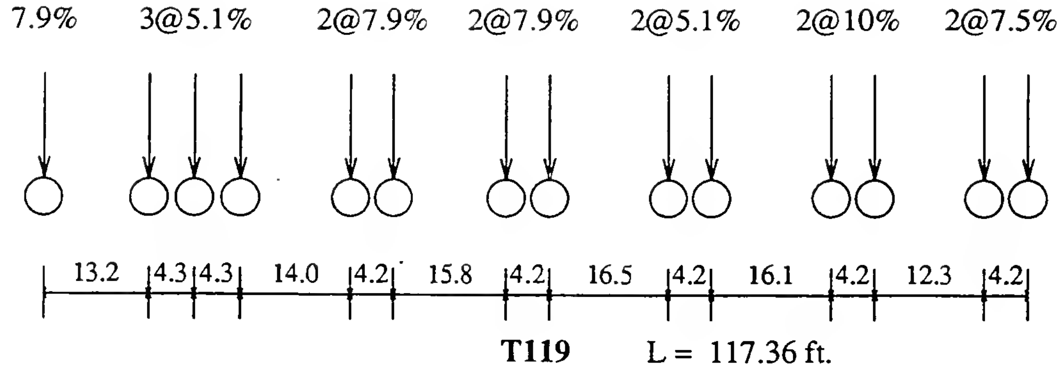


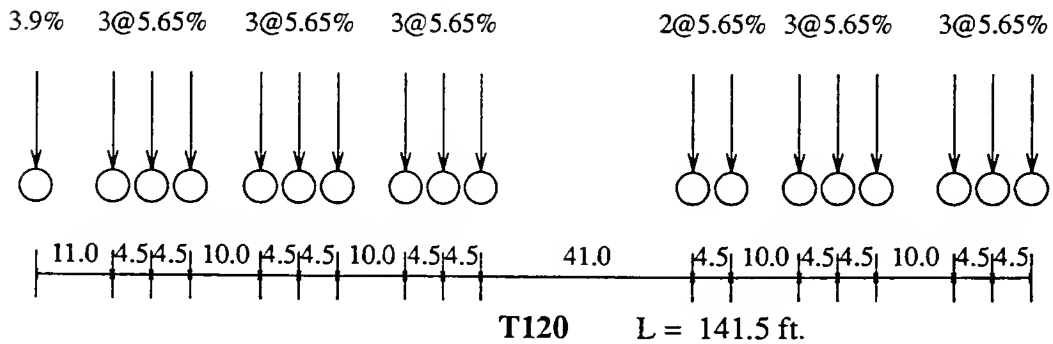
T117 L = 87.5 ft.



T118 L = 147.82 ft.

Figure 2.7 continued.





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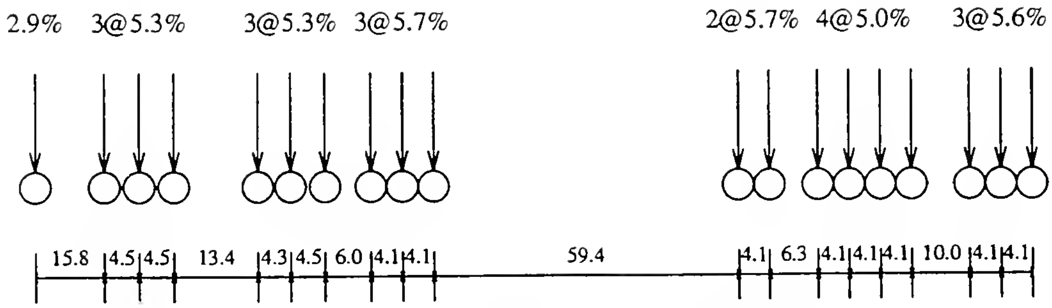
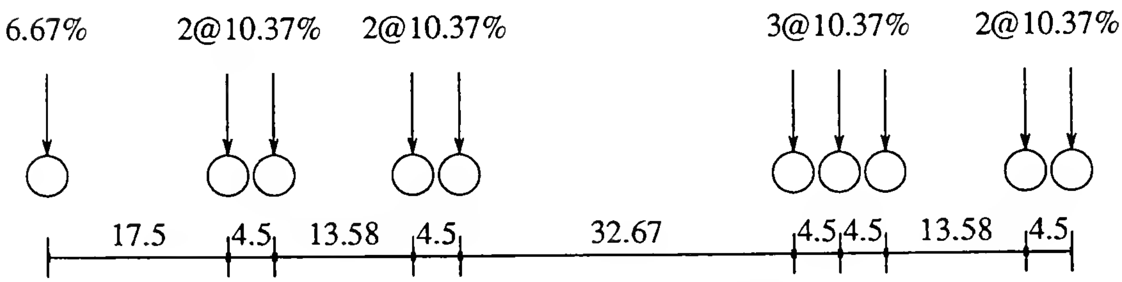
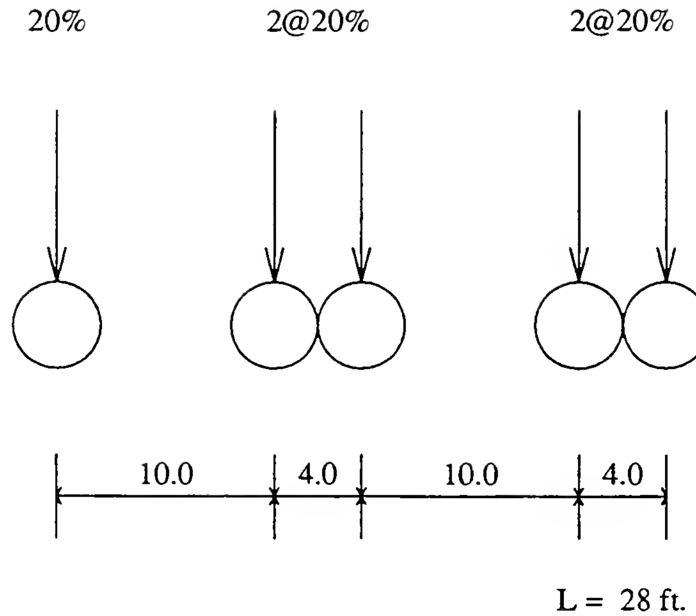


T121 L = 161.37 ft.

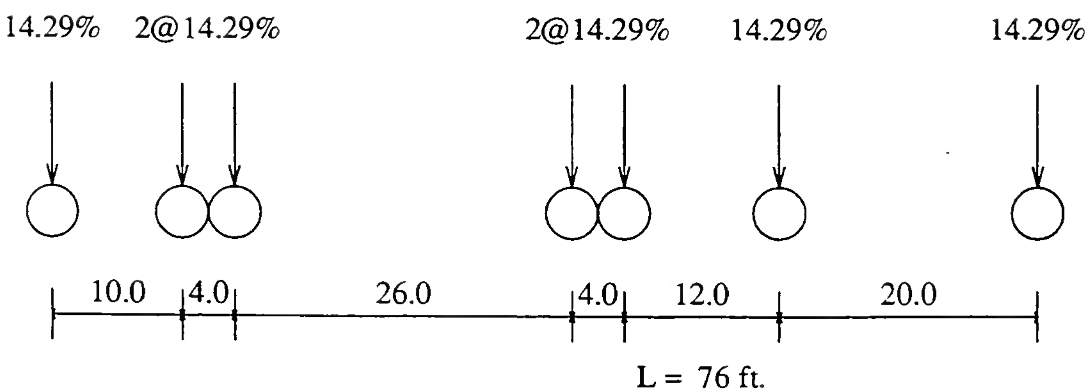


T122 L = 99.83 ft.

Figure 2.7 continued.

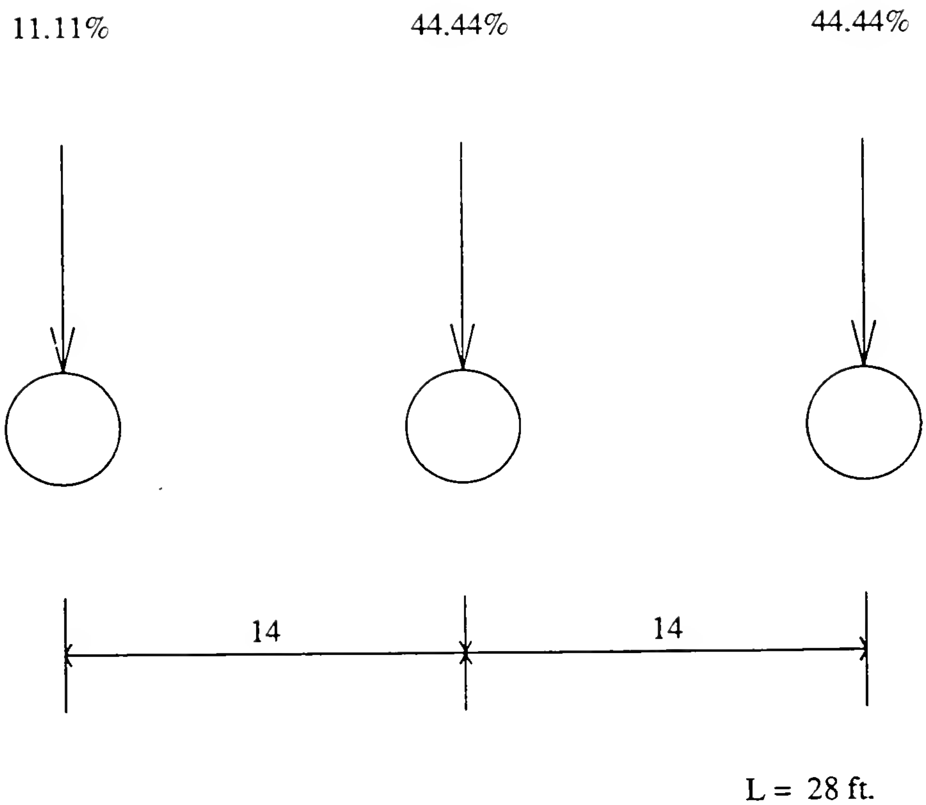


T123, Indiana toll road vehicle



T124, Indiana toll road vehicle

Figure 2.7 continued.



T125, HS20-44 Design Vehicle

Figure 2.7 continued.

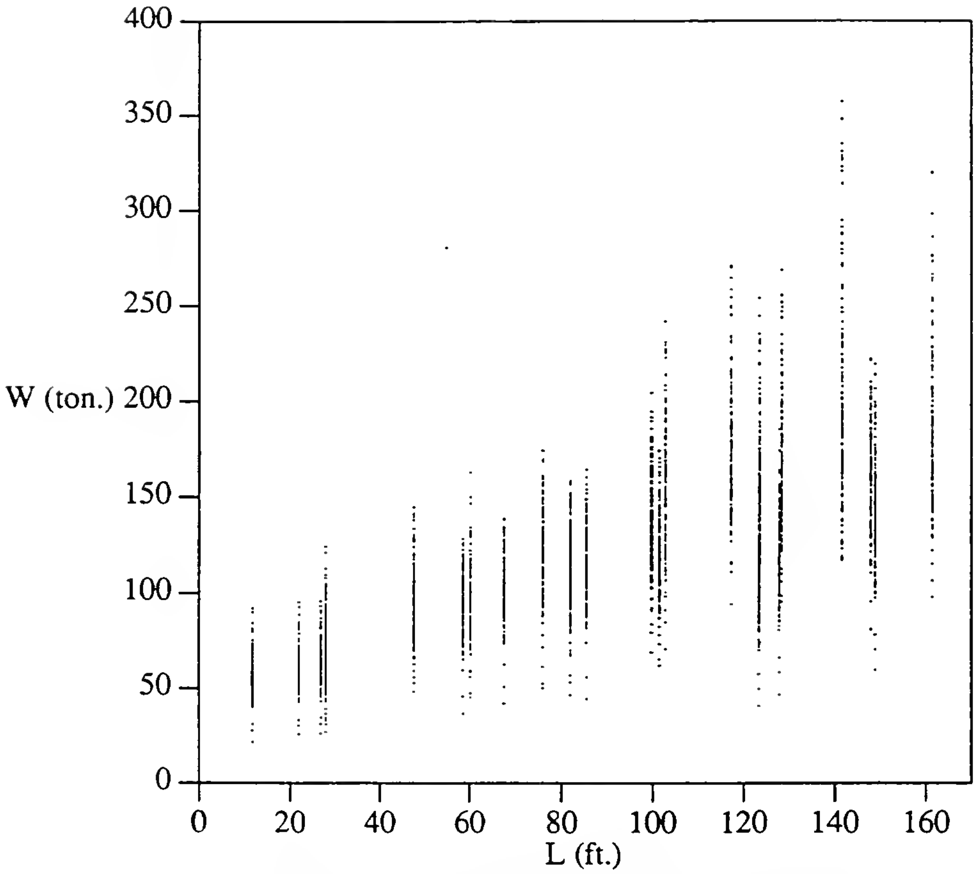


Figure 3.1 Allowable load, W, vs. wheel base, L, for $10 \le L \le 160$ ft.

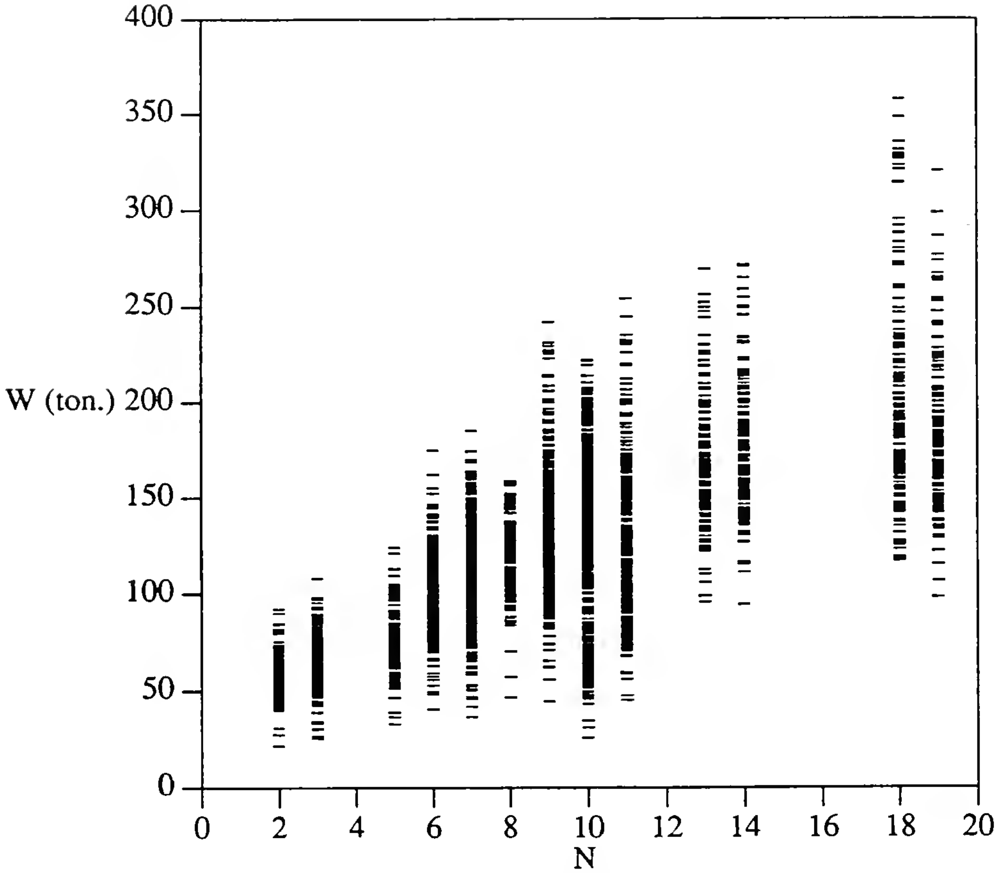


Figure 3.2 Allowable load, W, vs. number of axles, N, for $10 \leq L \leq 160$ ft.

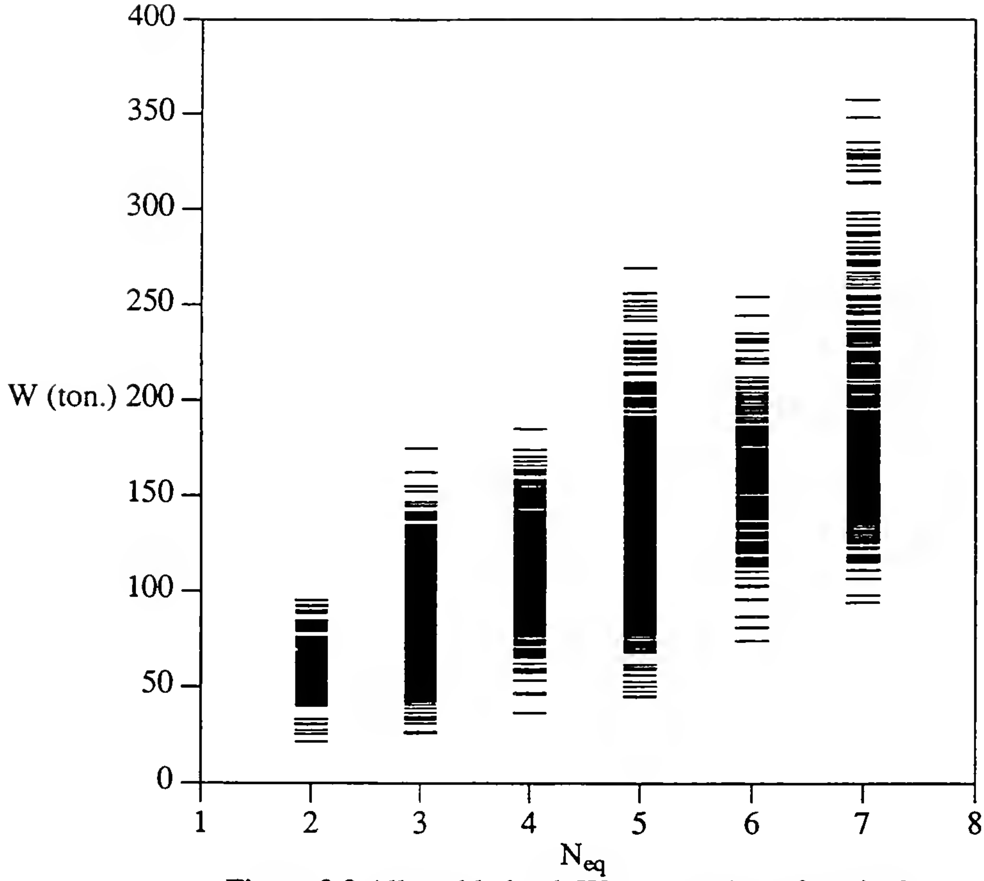


Figure 3.3 Allowable load, W, vs. number of equivalent axles, N_{eq}, for $10 \leq L \leq 160$ ft.

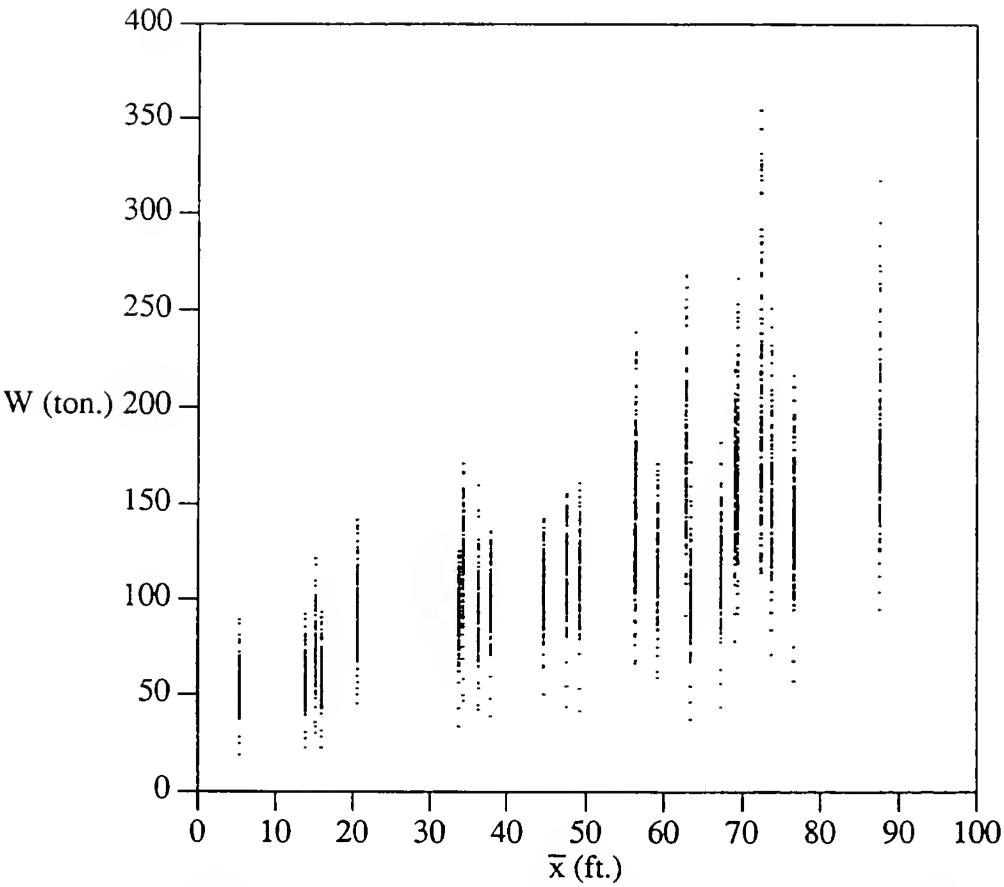


Figure 3.4 Allowable load, W, vs. distance of resultant truck load from front axle, $\bar{x}$, for $10 \leq L \leq 160$ ft.

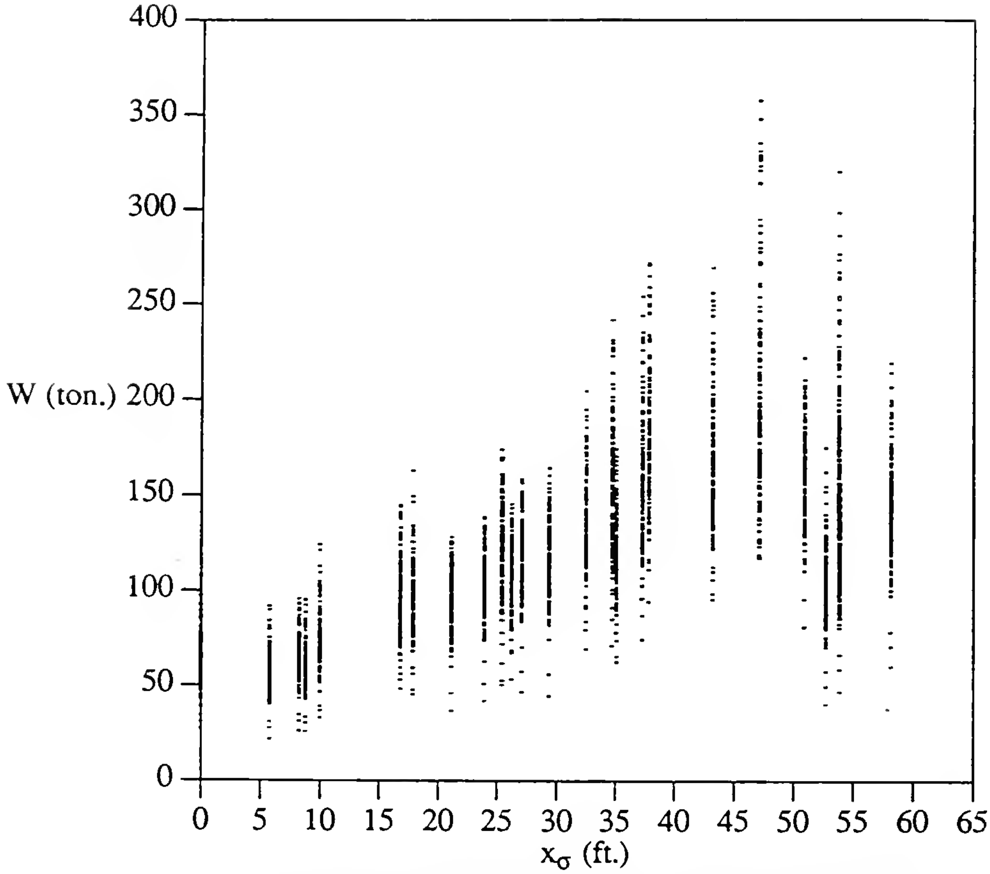


Figure 3.5 Allowable load, W, vs. the standard deviation of truck load distribution, x_σ, for $10 \leq L \leq 160$ ft.

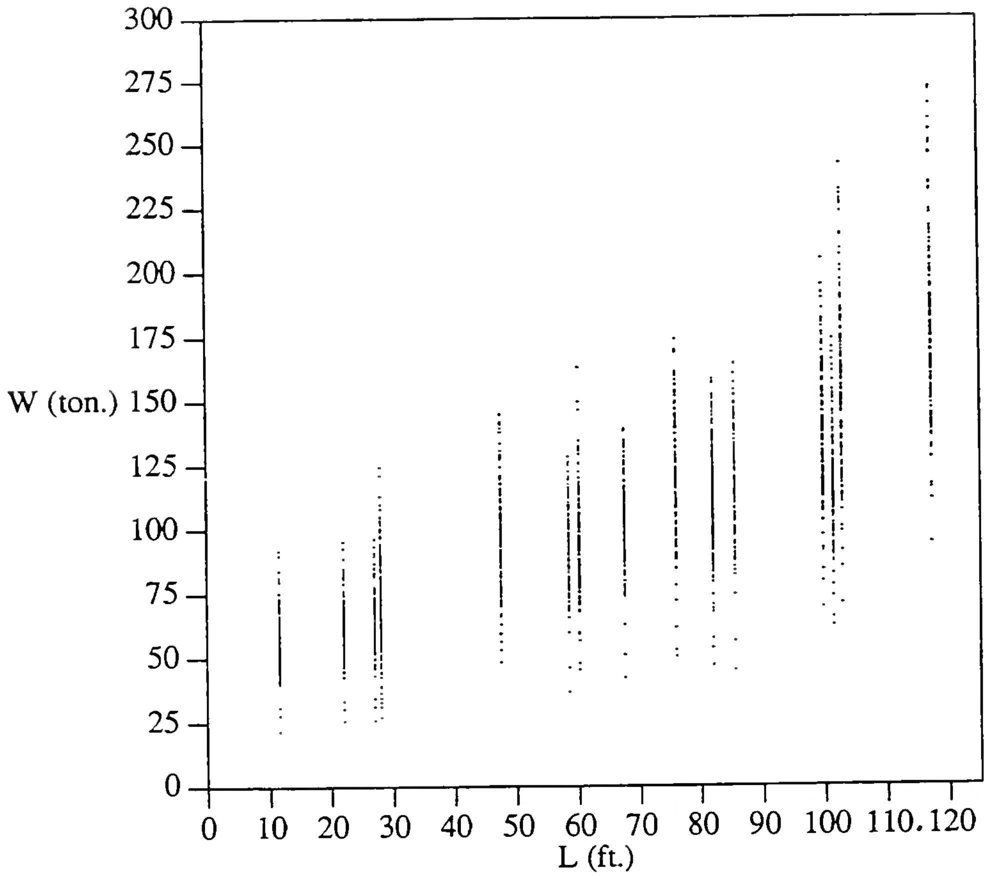


Figure 3.6 Allowable load, W, vs. wheel base, L,
for $10 \leq L \leq 120$ ft.

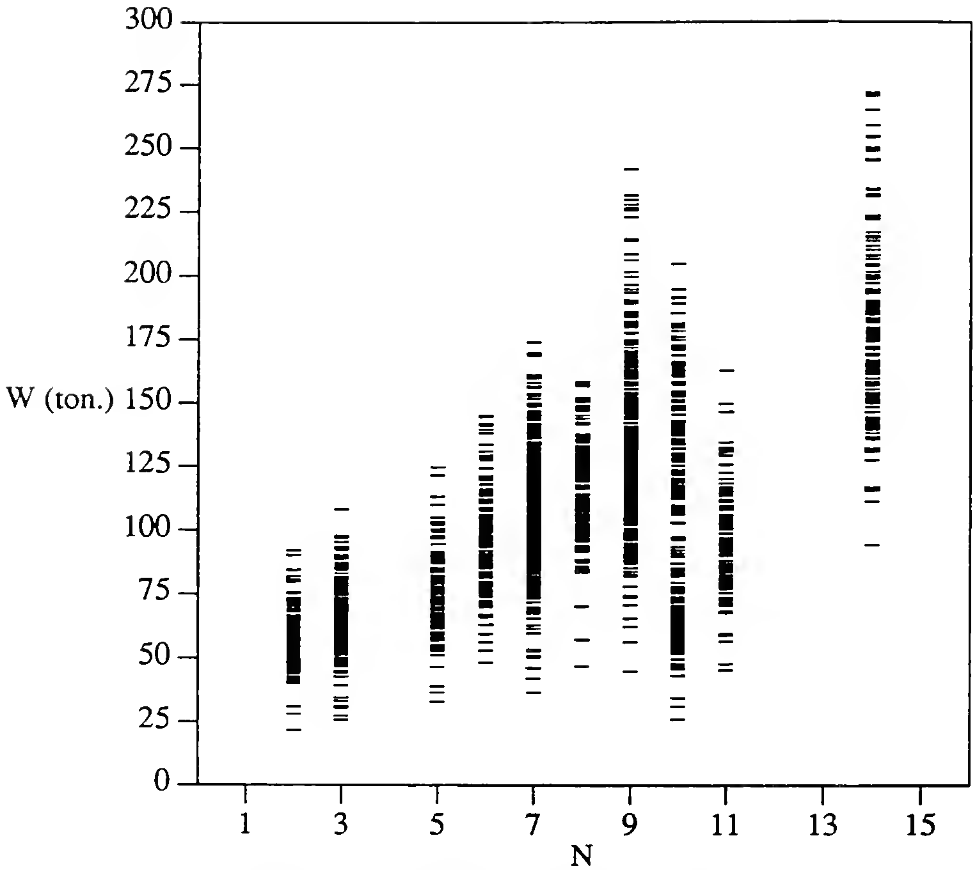


Figure 3.7 Allowable load, W, vs. number of axles, N, for $10 \le L \le 120$ ft.

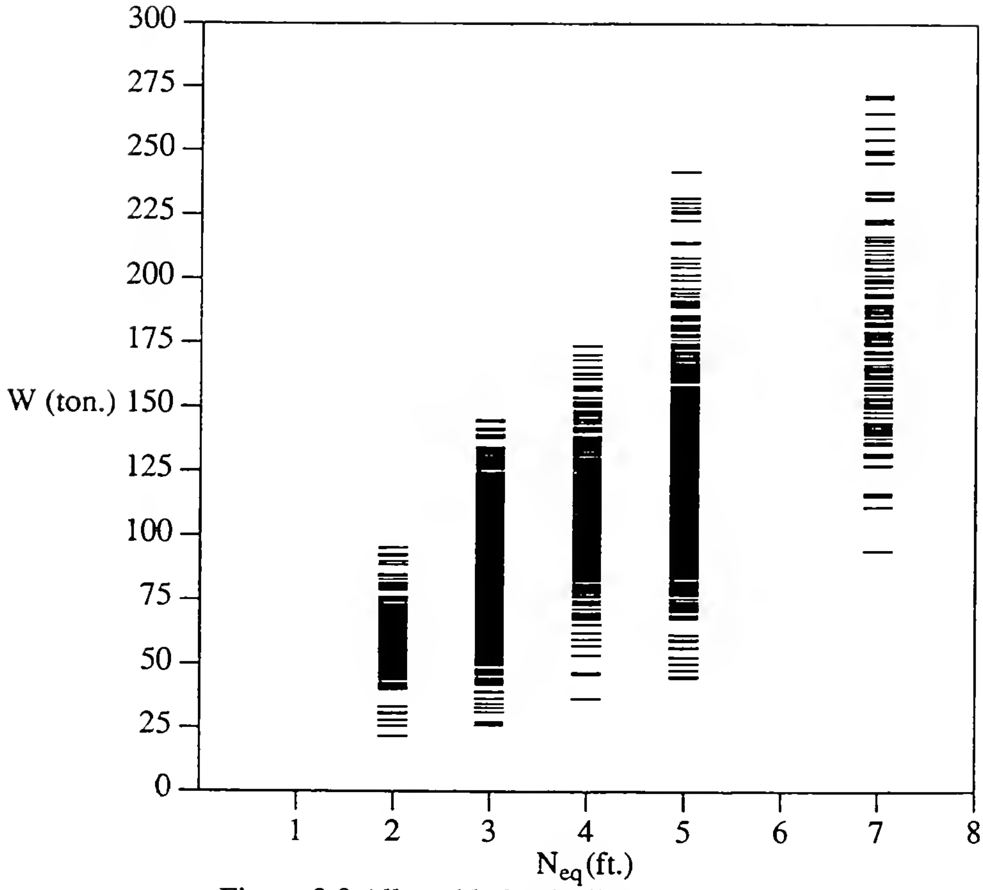


Figure 3.8 Allowable load, W, vs. number of equivalent axles, N_{eq} for $10 \le L \le 120$ ft.

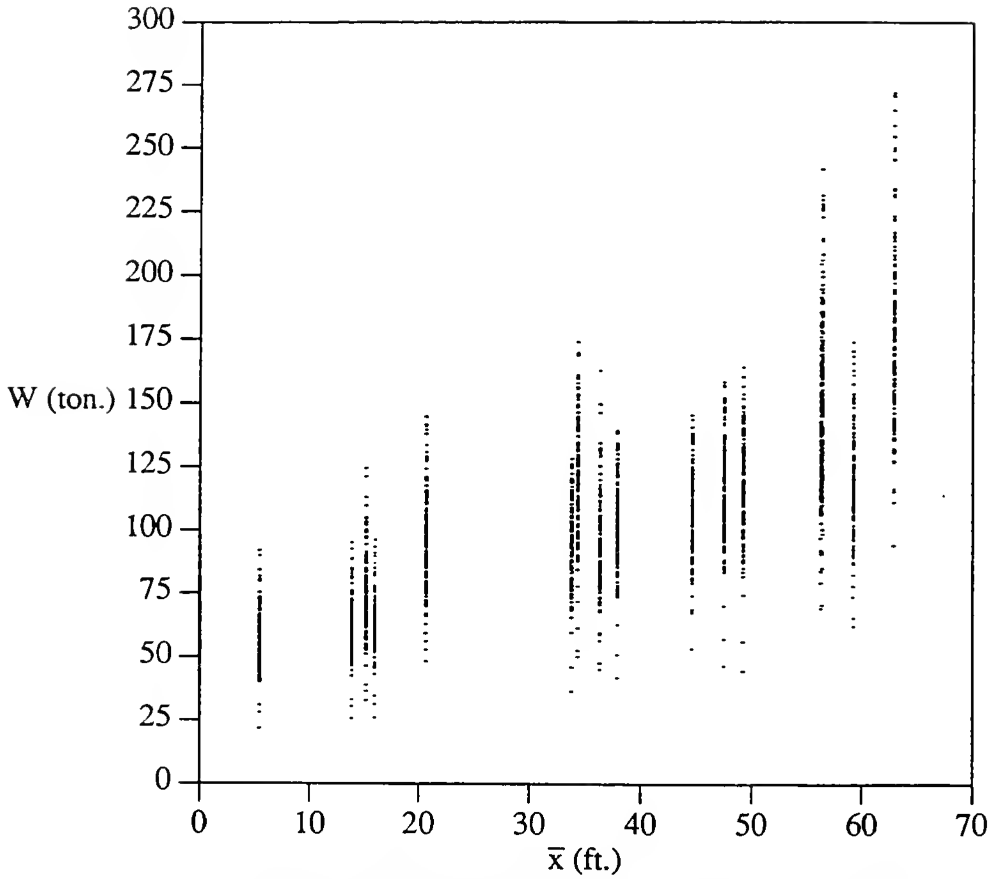


Figure 3.9 Allowable load, W, vs. distance of resultant truck load from front axle, $\bar{x}$, for $10 \leq L \leq 120$ ft.

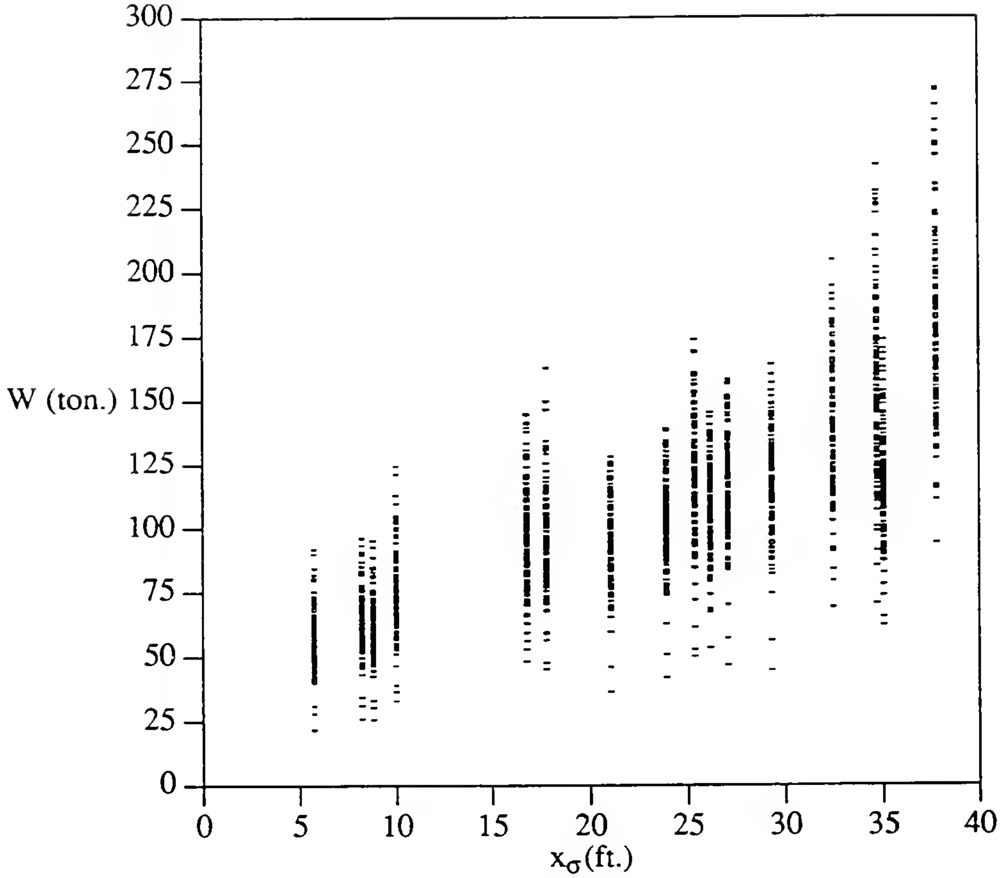


Figure 3.10 Allowable load, W, vs. standard deviation of truck load distribution, x_σ, for $10 \leq L \leq 120$ ft.

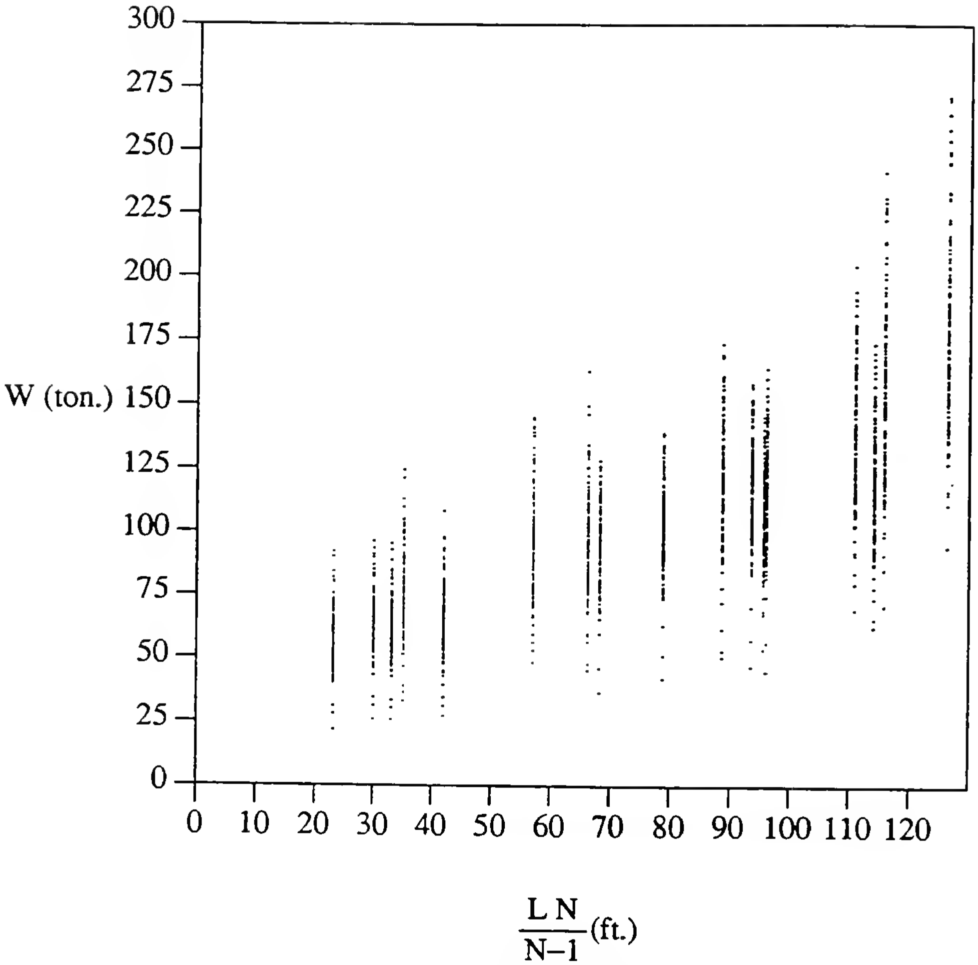


Figure 3.11 Allowable load, W, vs. $\frac{L\,N}{N-1}$ for $10 \le L \le 120$ ft.

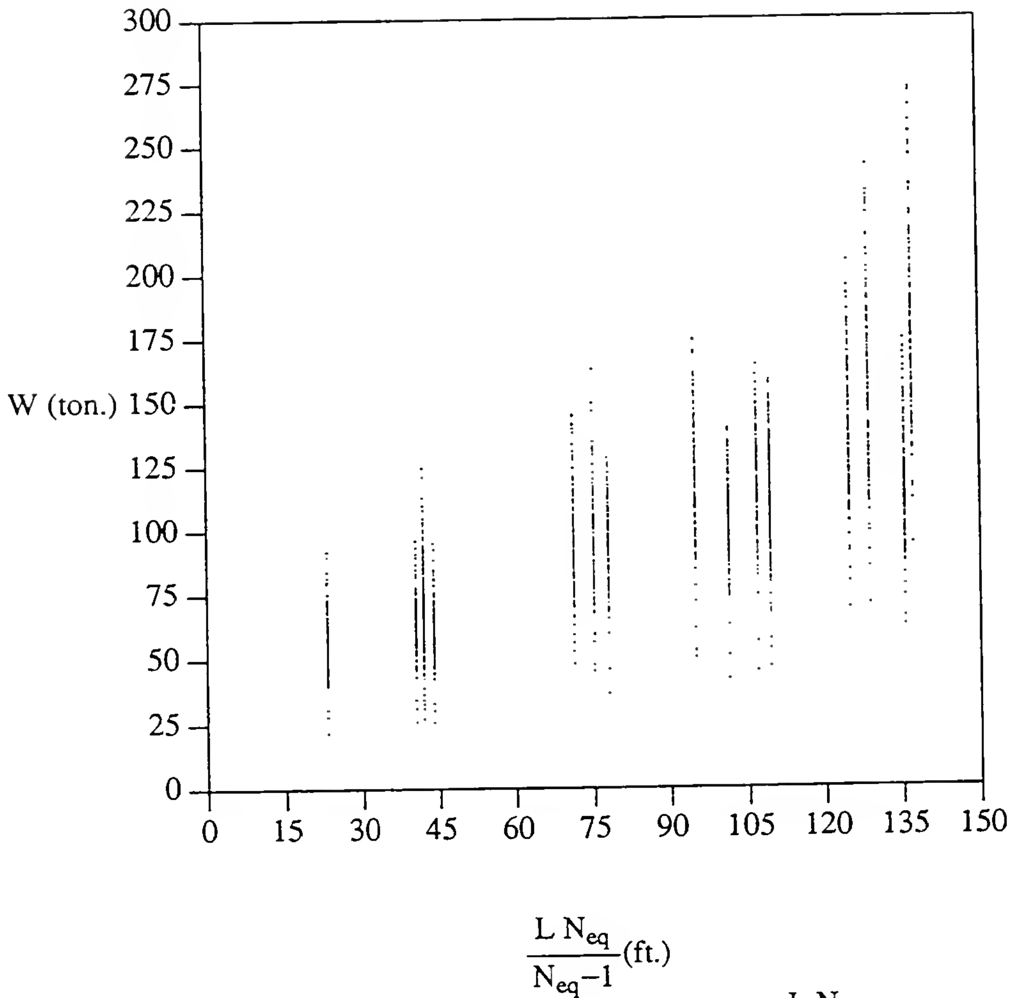


Figure 3.12 Allowable load, W, vs. $\frac{L\,N_{eq}}{N_{eq}-1}$ for $10 \le L \le 120$ ft.

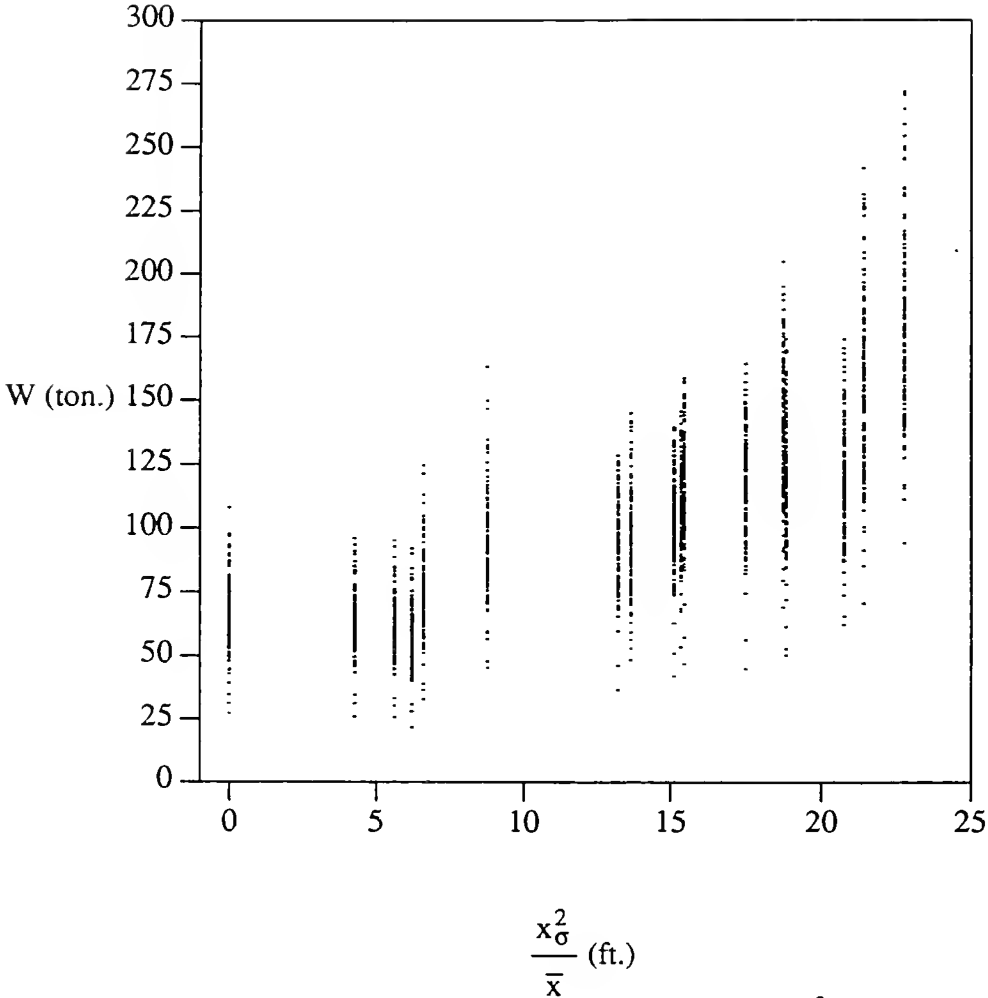


Figure 3.13 Allowable load, W, vs. $\frac{x_\sigma^2}{\bar{x}}$
for $10 \le L \le 120$ ft.

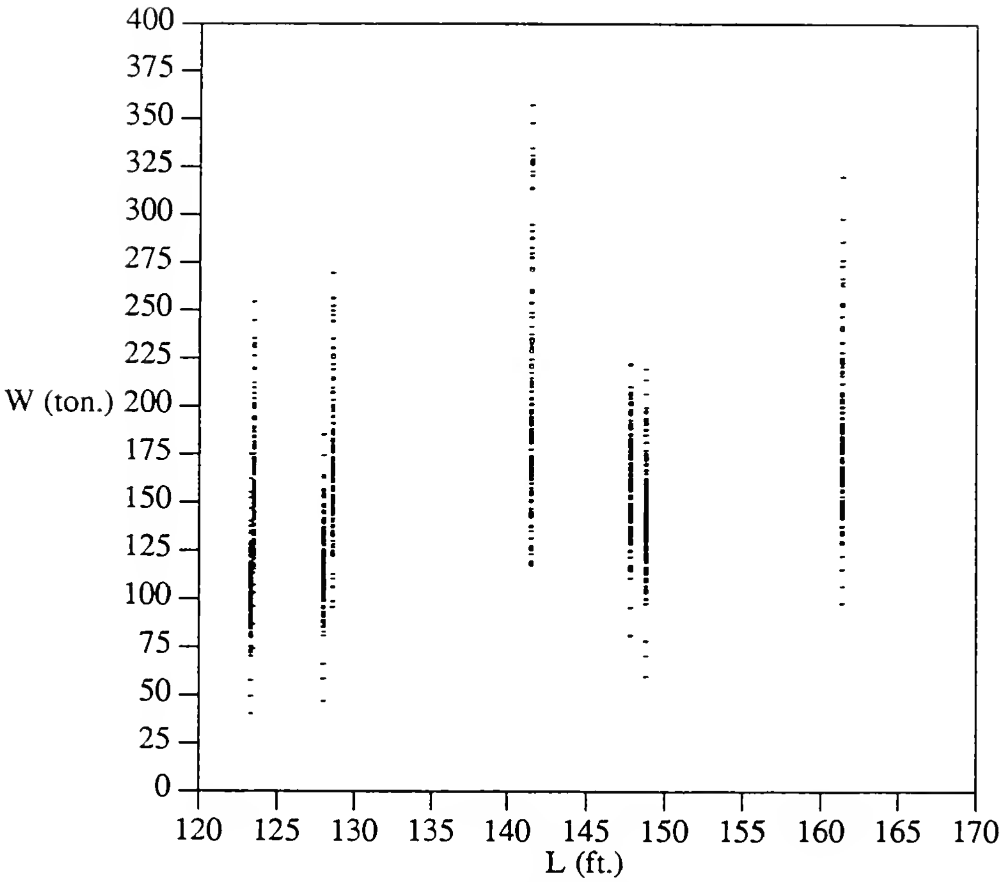


Figure 3.14 Allowable load, W, vs. wheel base, L, for 120 < L ≤ 160 ft.

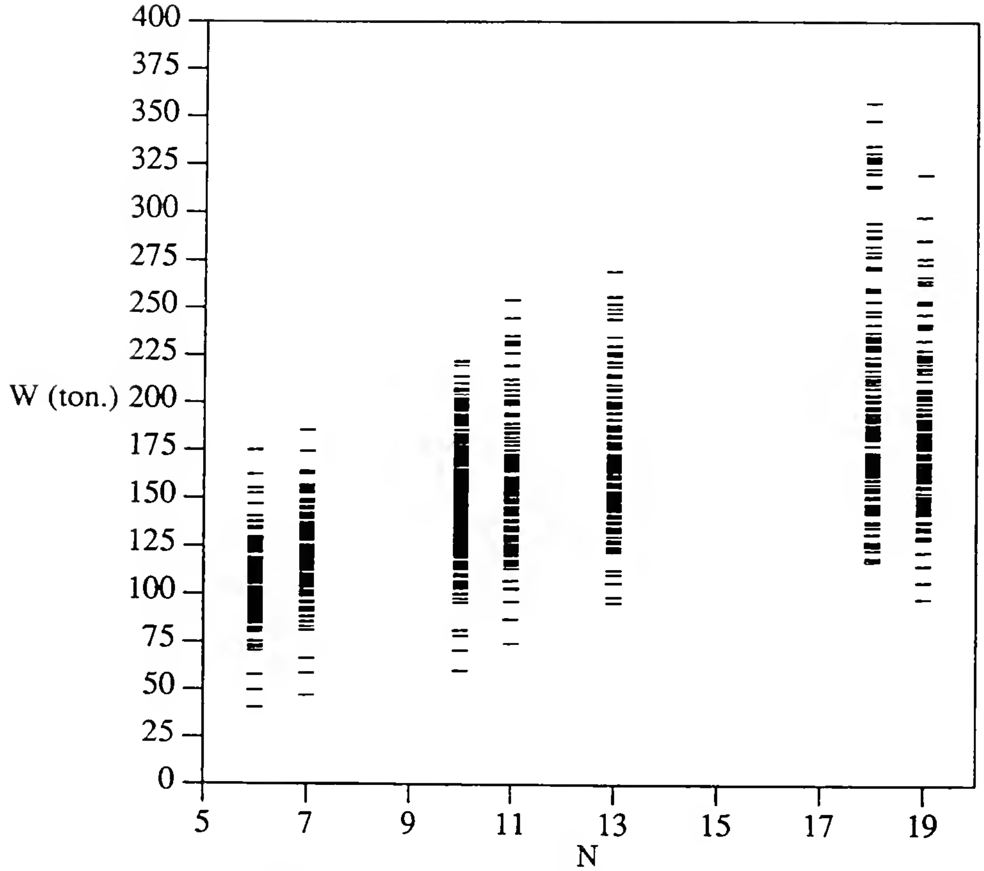


Figure 3.15 Allowable load, W, vs. number of axles, N, for $120 < L \leq 160$ ft.

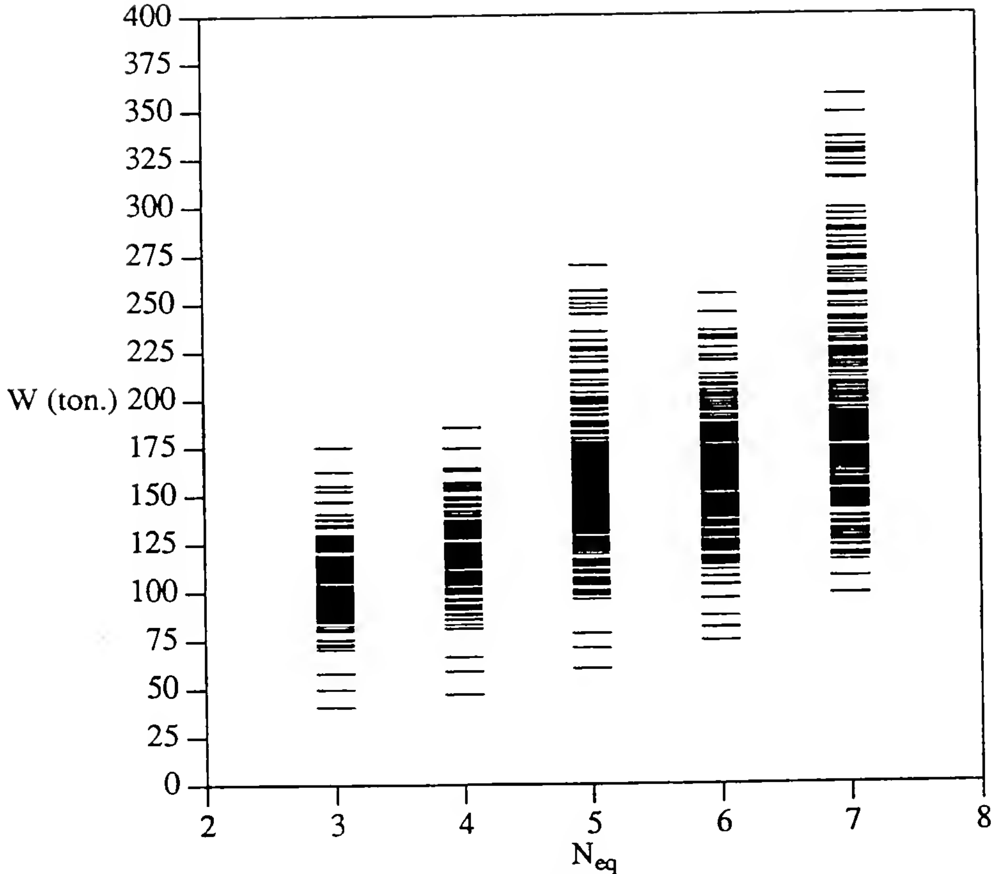


Figure 3.16 Allowable load, W, vs. number of equivalent axles, N_{eq} for $120 < L \leq 160$ ft.

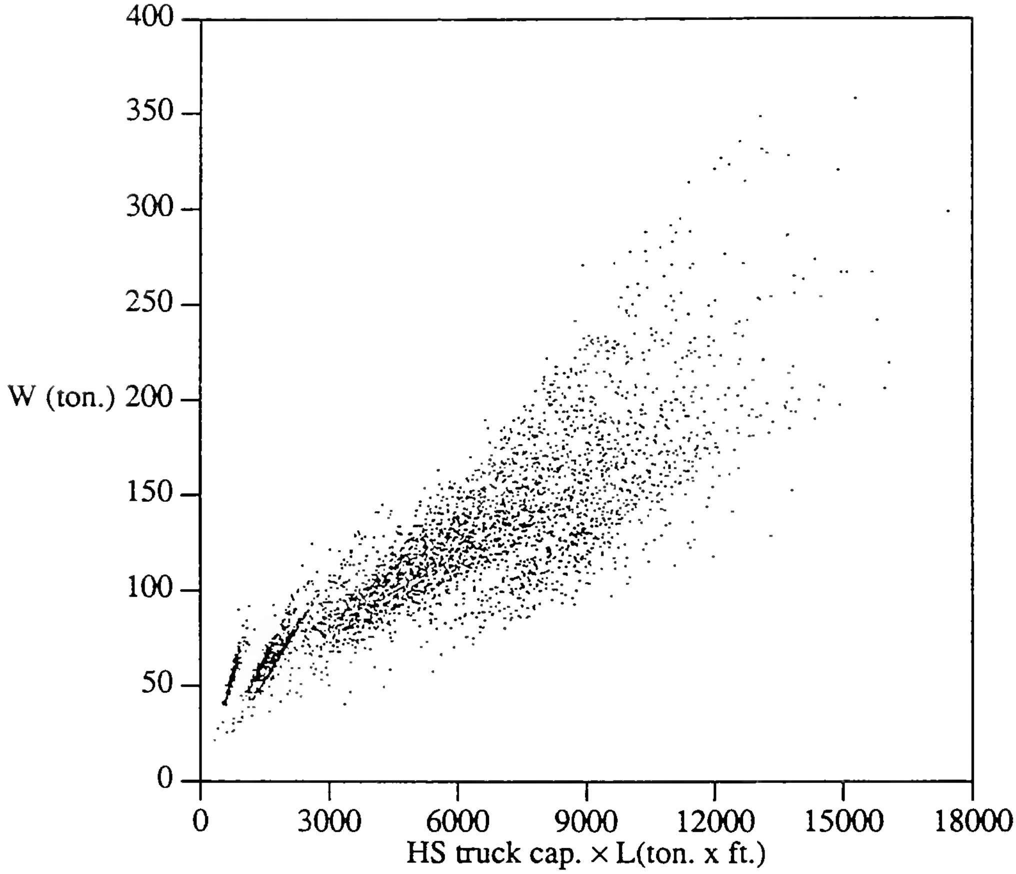


Figure 3.17 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for $10 \leq L \leq 160$ ft.

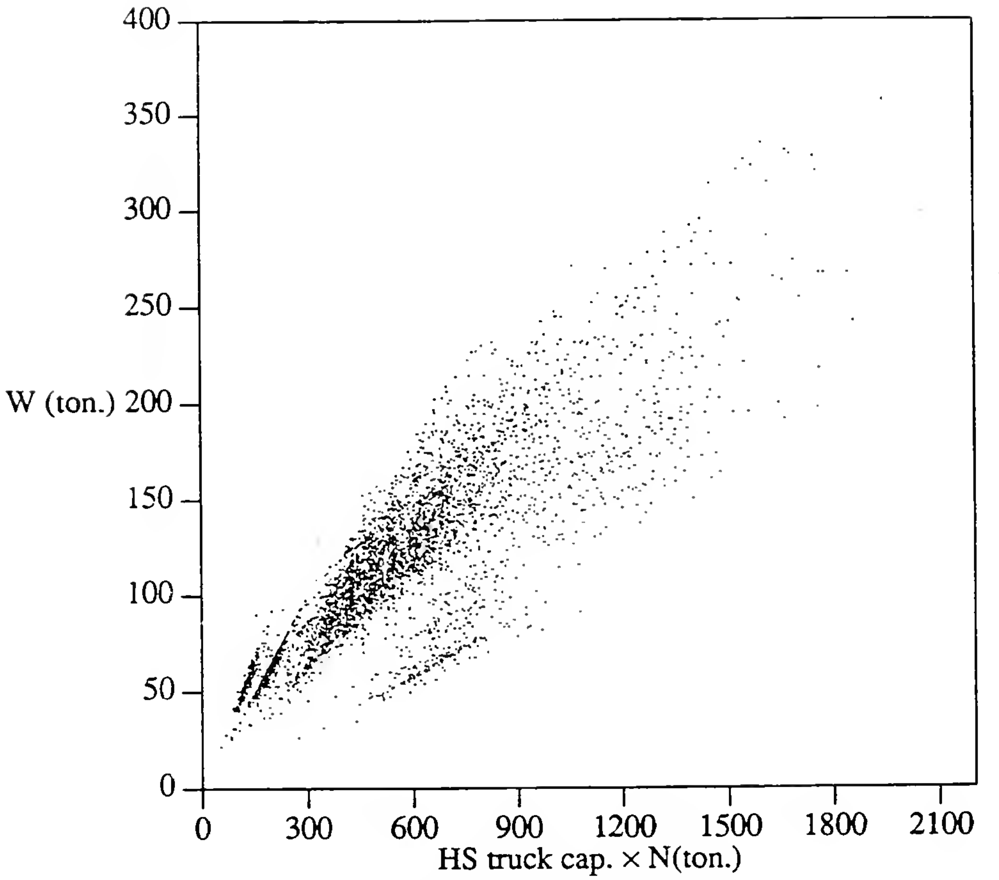


Figure 3.18 Allowable load, W, vs. the product of HS truck capacity and number of axles, N, for $10 \leq L \leq 160$ ft.

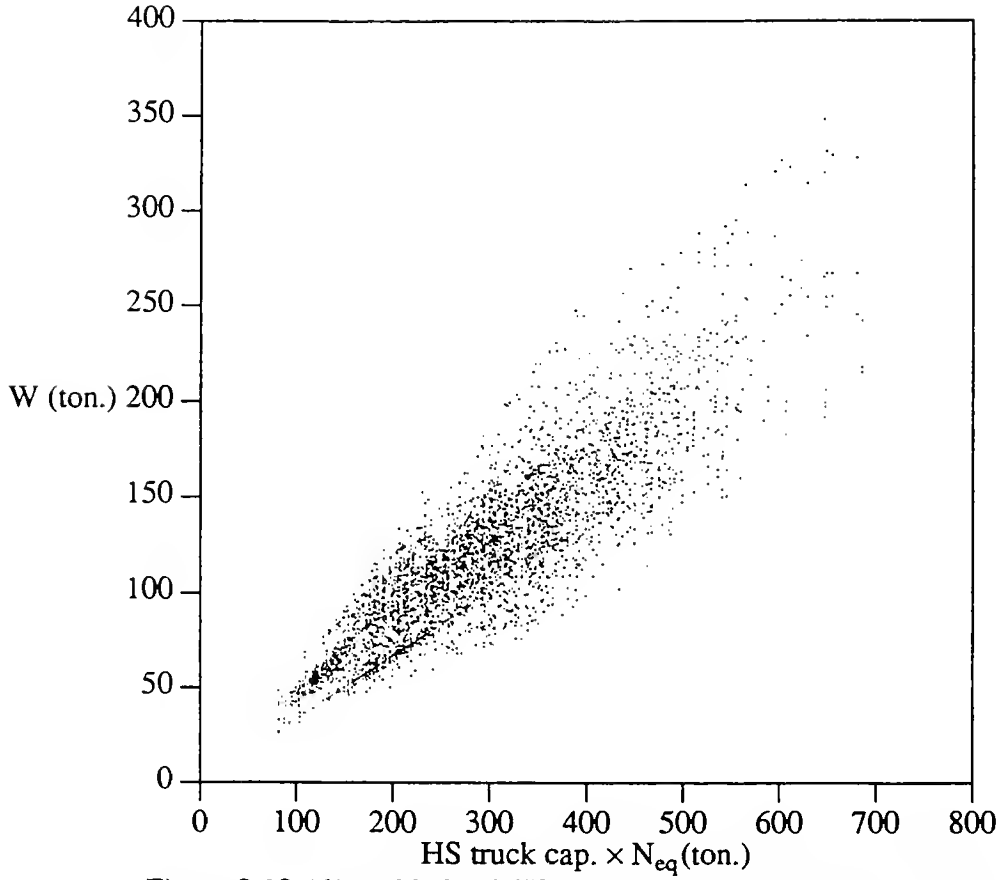


Figure 3.19 Allowable load, W, vs. the product of HS truck capacity and number of equivalent axles, N_{eq}, for $10 \leq L \leq 160$ ft.

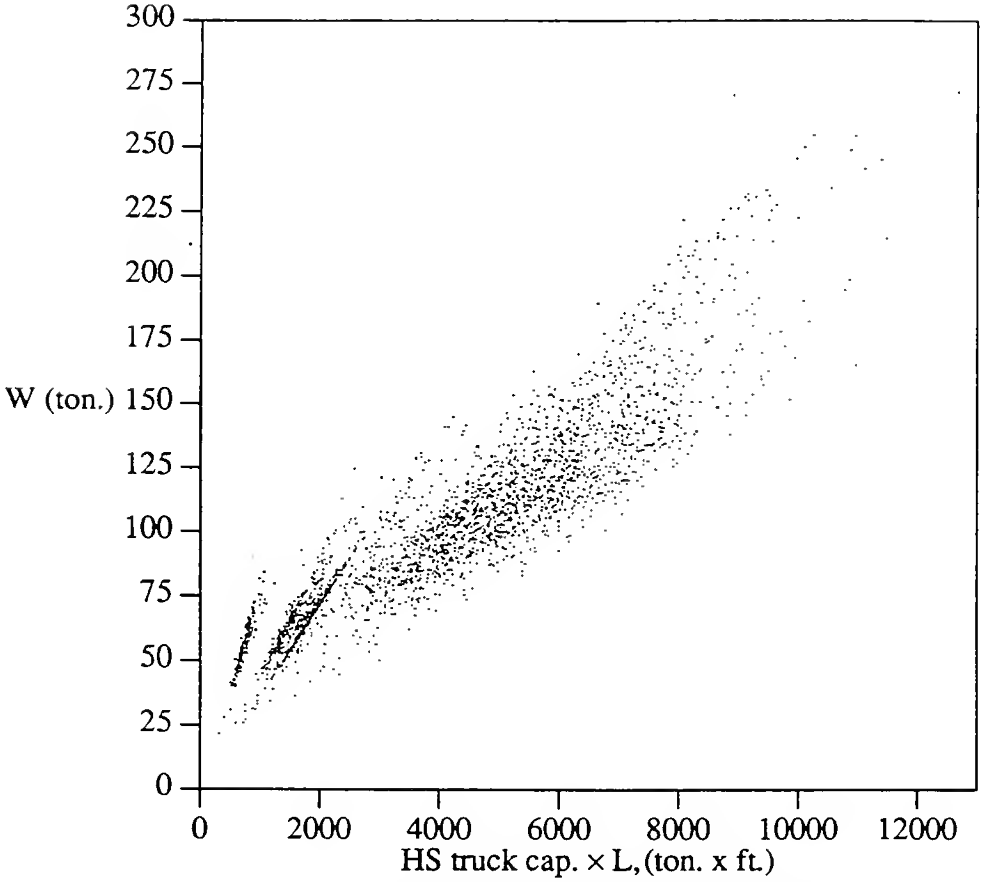


Figure 3.20 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for $10 \leq L \leq 120$ ft.

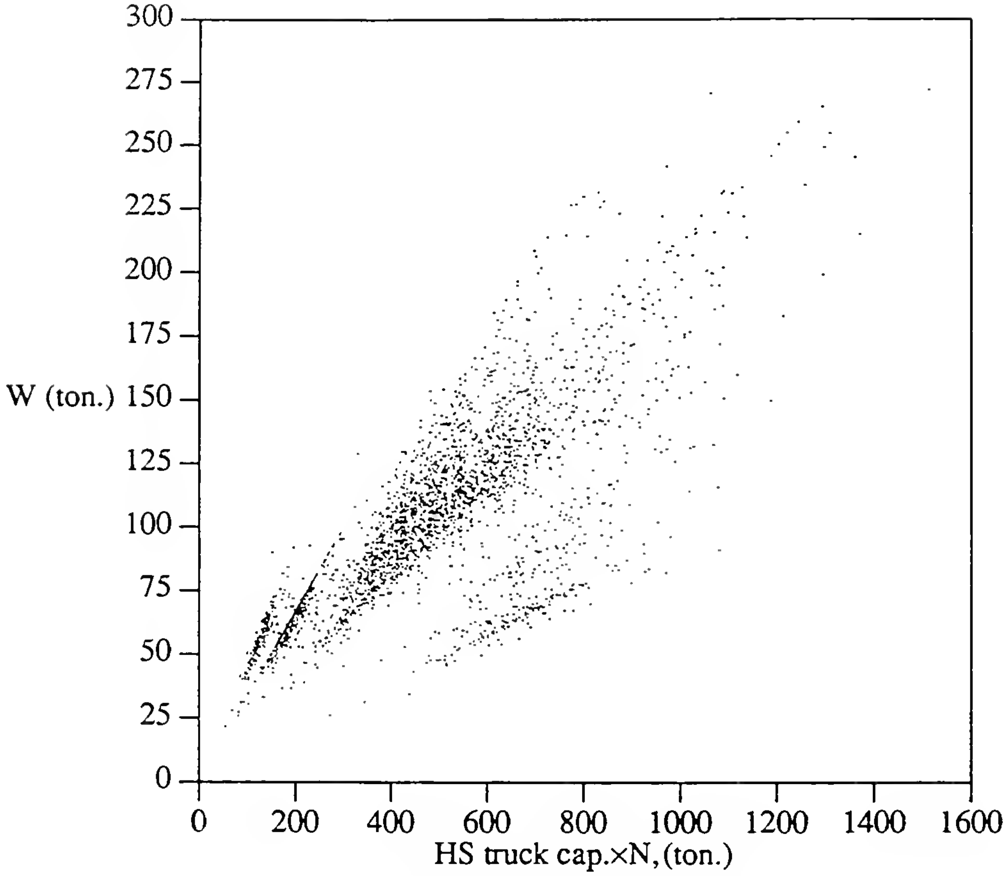


Figure 3.21 Allowable load, W, vs. the product of HS truck capacity and number of axles, N, for $10 \leq L \leq 120$ ft.

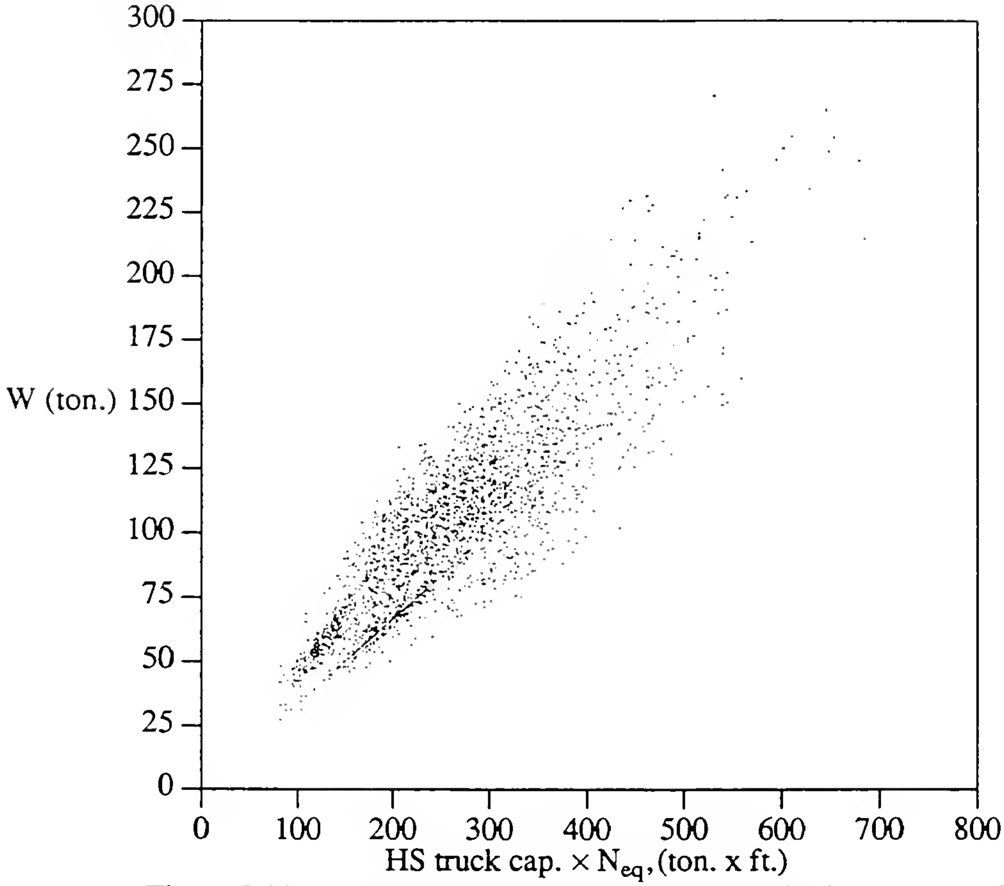


Figure 3.22 Allowable load, W, vs. the product of HS truck capacity and number of equivalent axles, N_{eq}, for $10 \le L \le 120$ ft.

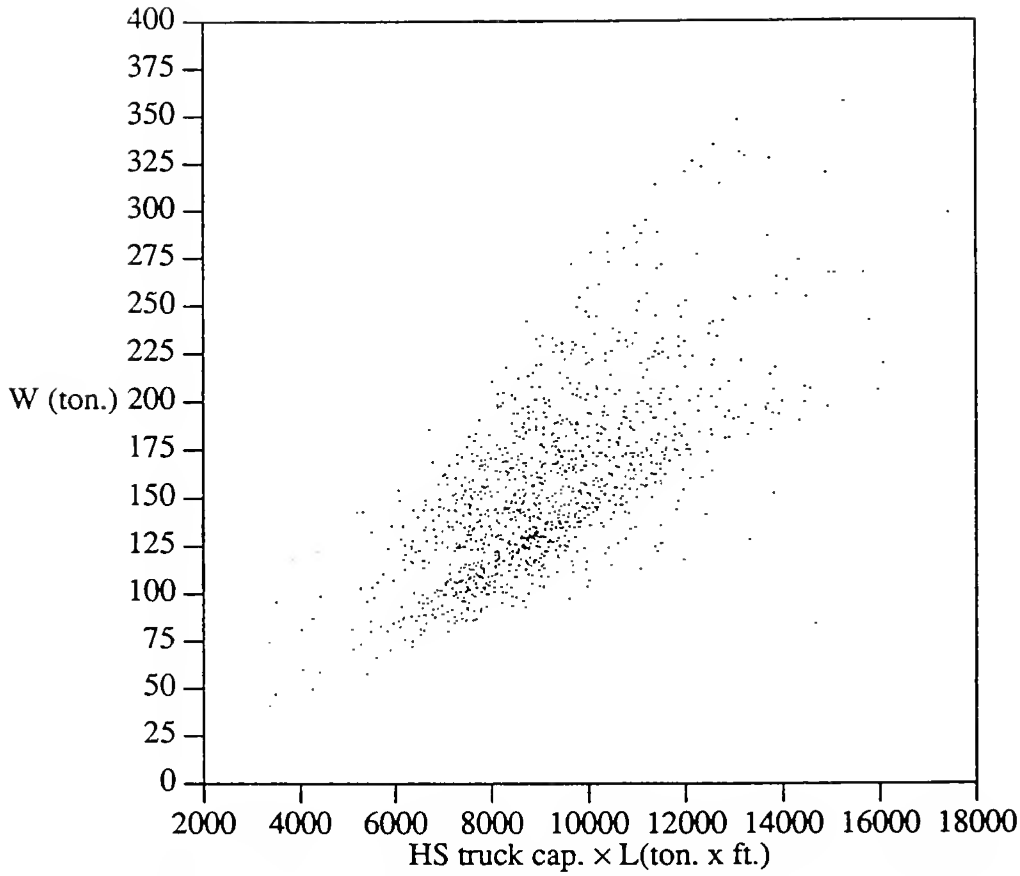


Figure 3.23 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for 120 < L ≤ 160 ft.

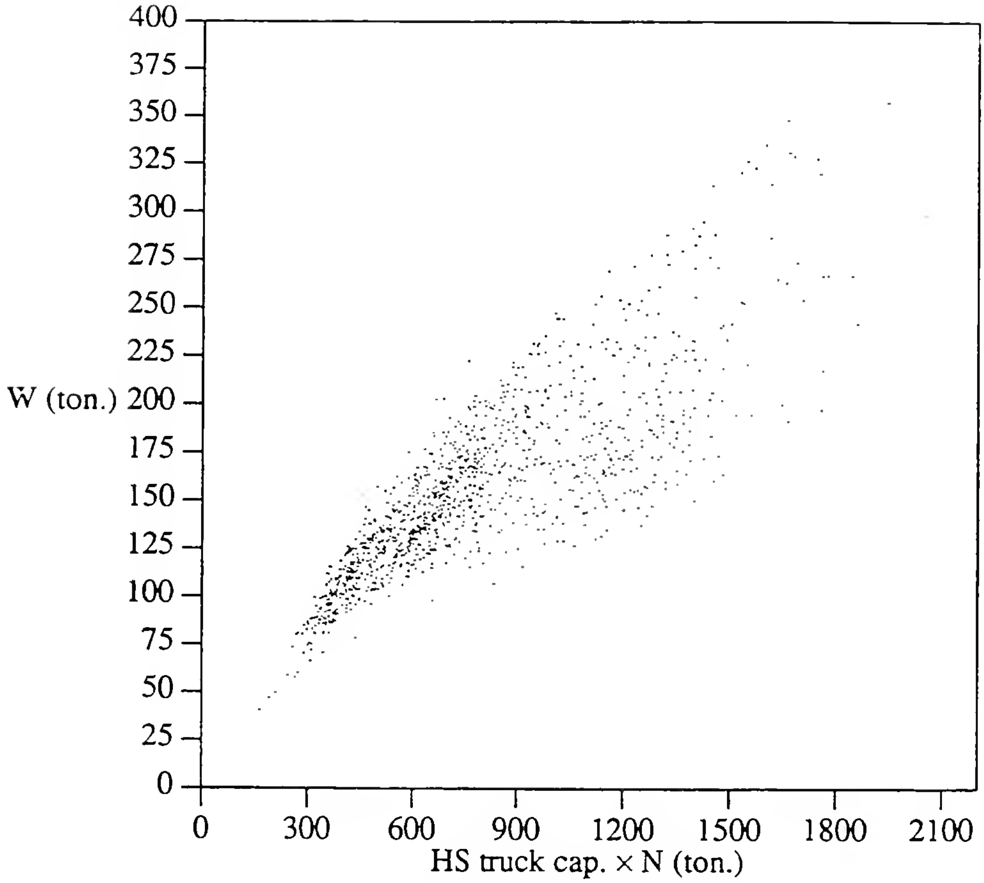


Figure 3.24 Allowable load, W, vs. the product of HS truck capacity and number of axles, N, for $120 < L \leq 160$ ft.

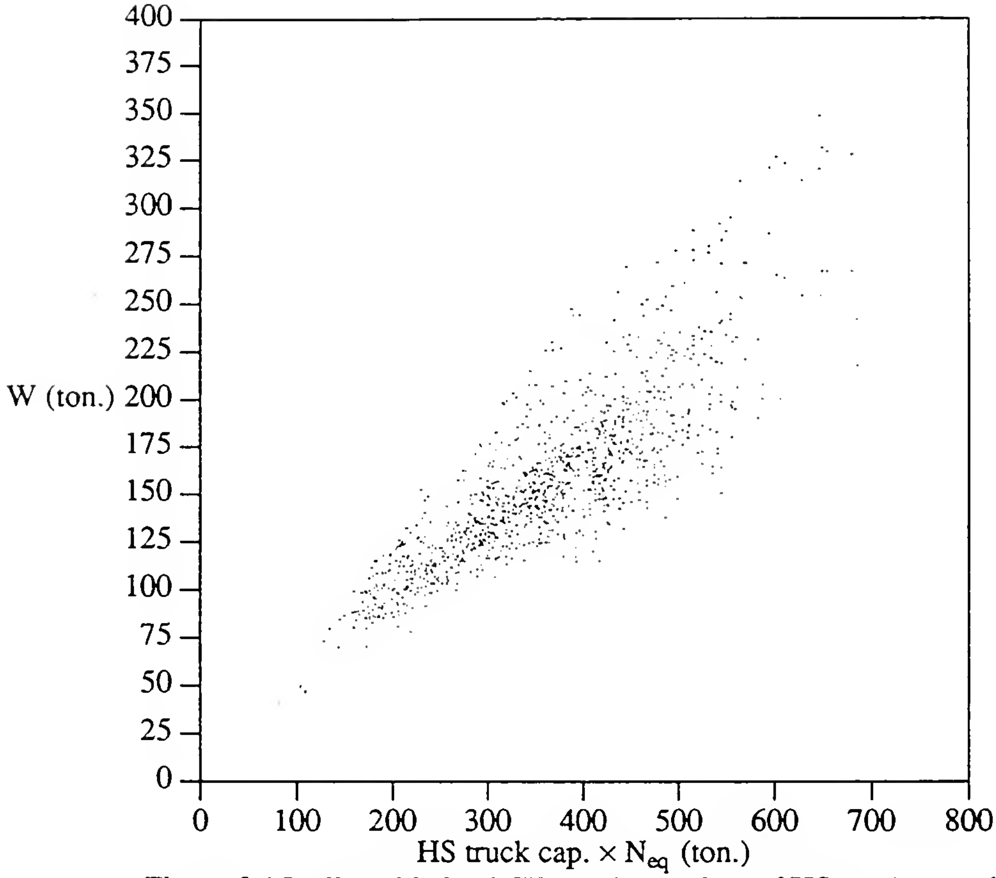


Figure 3.25 Allowable load, W, vs. the product of HS truck capacity and number of equivalent axles, N_{eq} for $120 < L \leq 160$ ft.

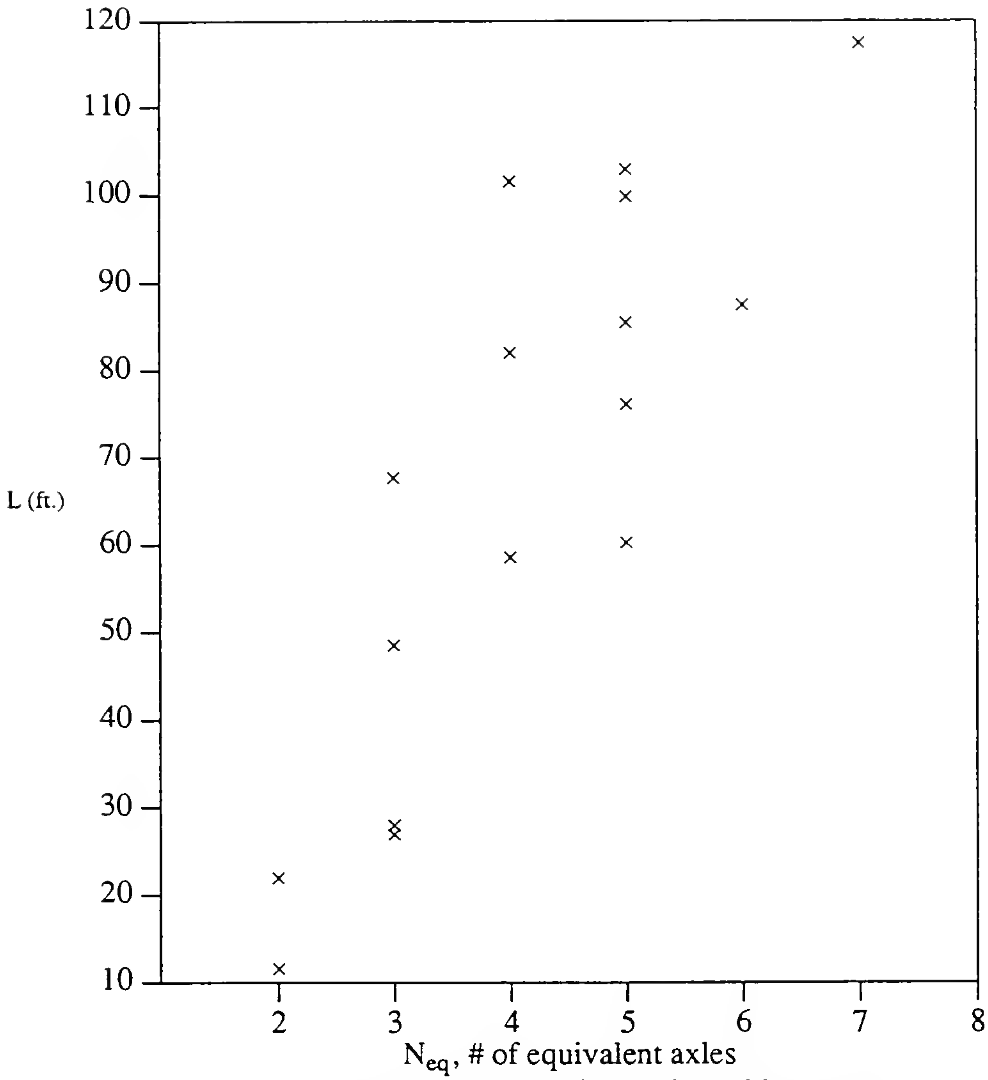


Figure 3.26 Truck sample distribution with respect to number of equivalent axles, N_{eq} and wheel base, L.

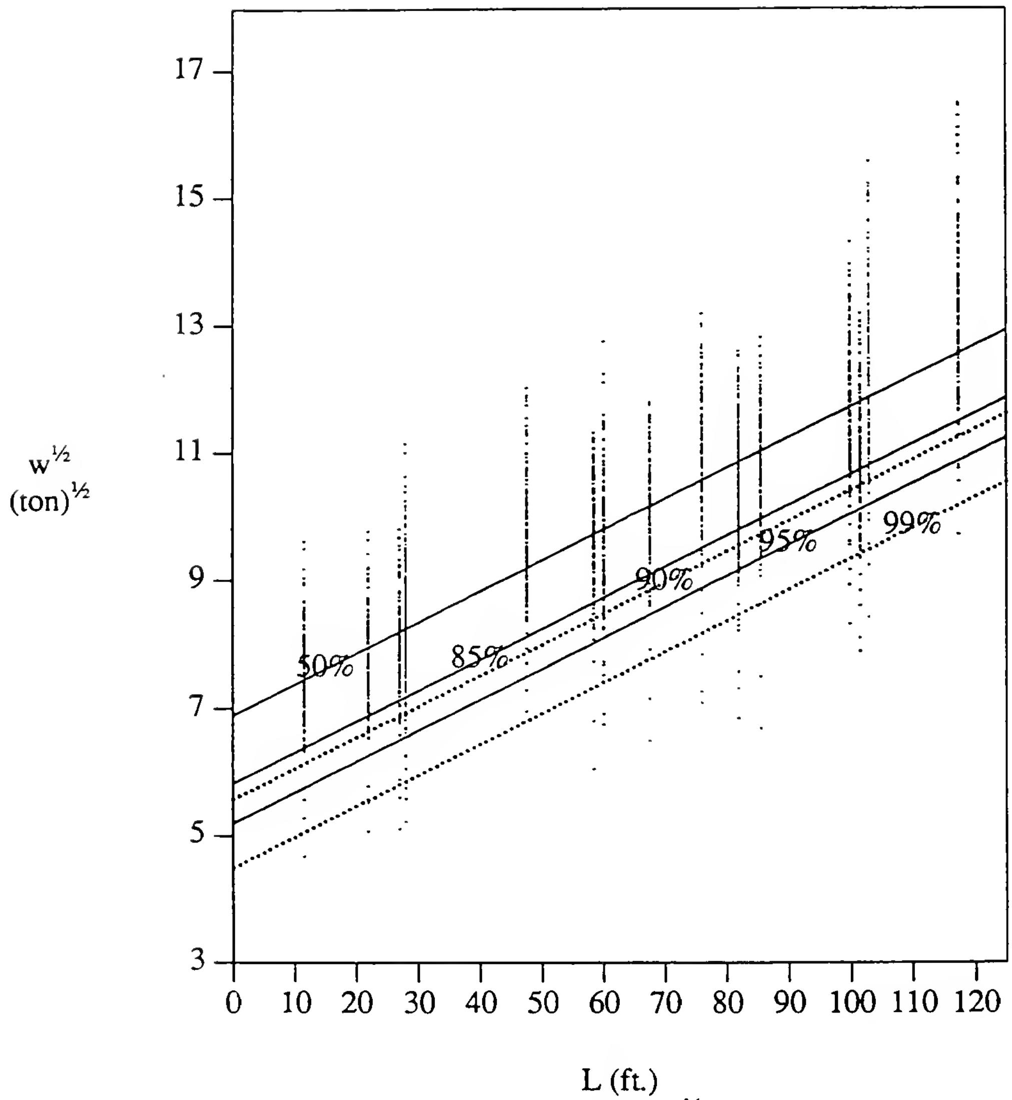


Figure 4.1 Transformed data, $w^{1/2}$, vs. Wheel Base, L, and the predicted $w^{1/2}$ at confidence levels 50%, 85%, 90%, 95%, and 99%.

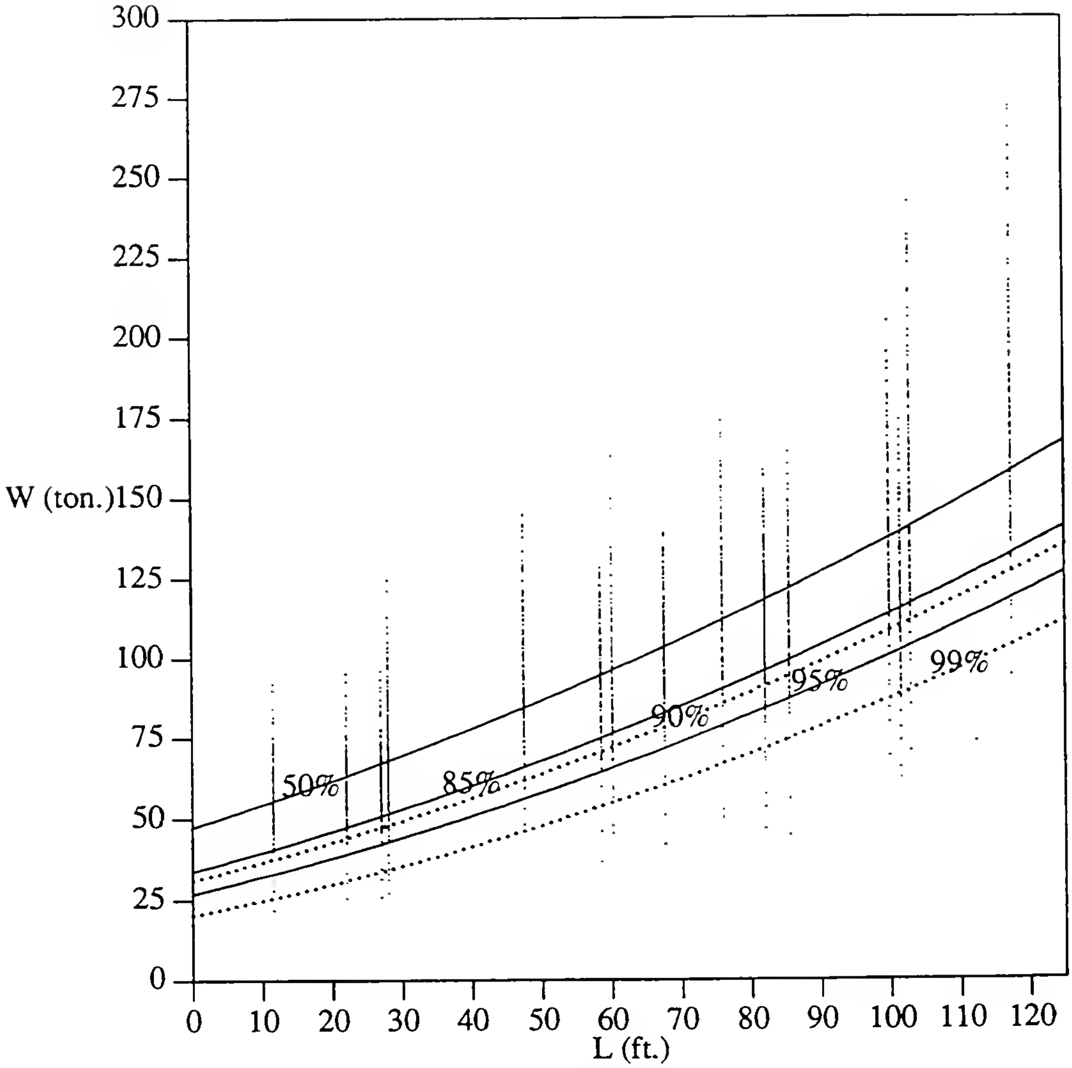
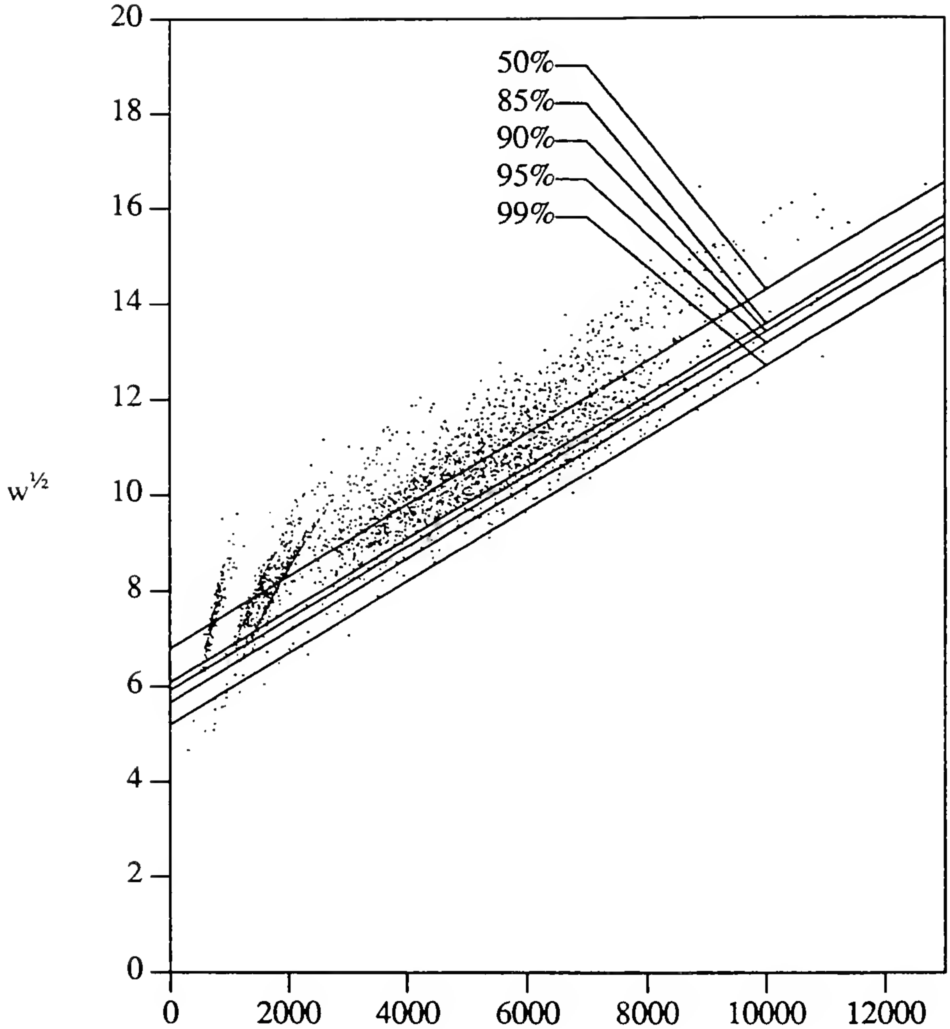


Figure 4.2 Allowable load, W, vs. Wheel Base, L, and the predicted allowable loads at confidence levels 50%, 85%, 90%, 95%, and 99%.



HS truck cap. x L (ton. x ft.)

Figure 4.3 Transformed data, $w^{1/2}$, vs. the product of HS truck capacity and Wheel Base, L, and the predicted $w^{1/2}$ at confidence levels 50%, 85%, 90%, 95%, and 99%.

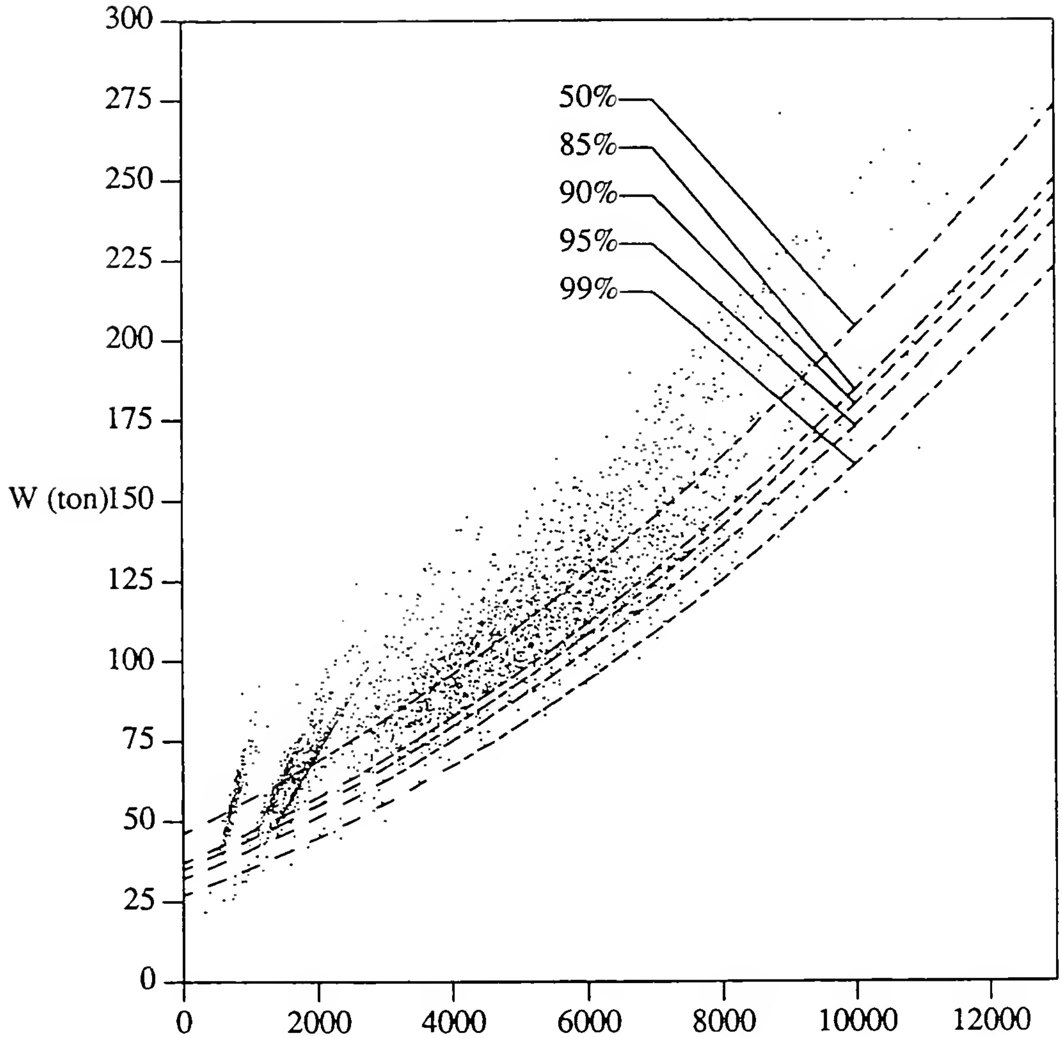


Figure 4.4 Allowable load, W, vs. the product of HS truck capacity and Wheel Base, L, and allowable load at confidence levels 50%, 85%, 90%, 95%, and 99%

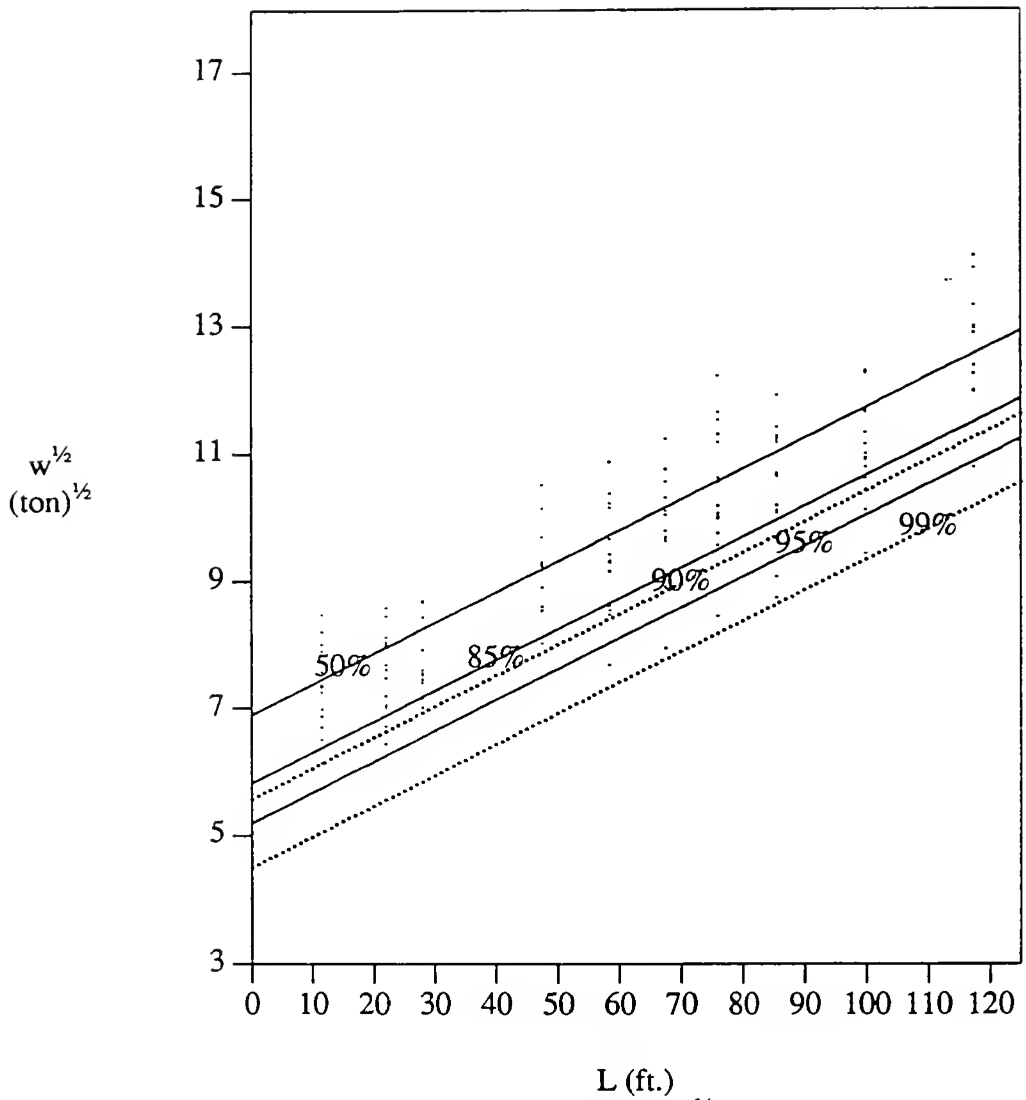


Figure 4.5 Transformed data, $w^{1/2}$, vs. Wheel Base, L, for test sample of bridges and the predicted $w^{1/2}$ at confidence levels 50%, 85%, 90%, 95%, and 99%

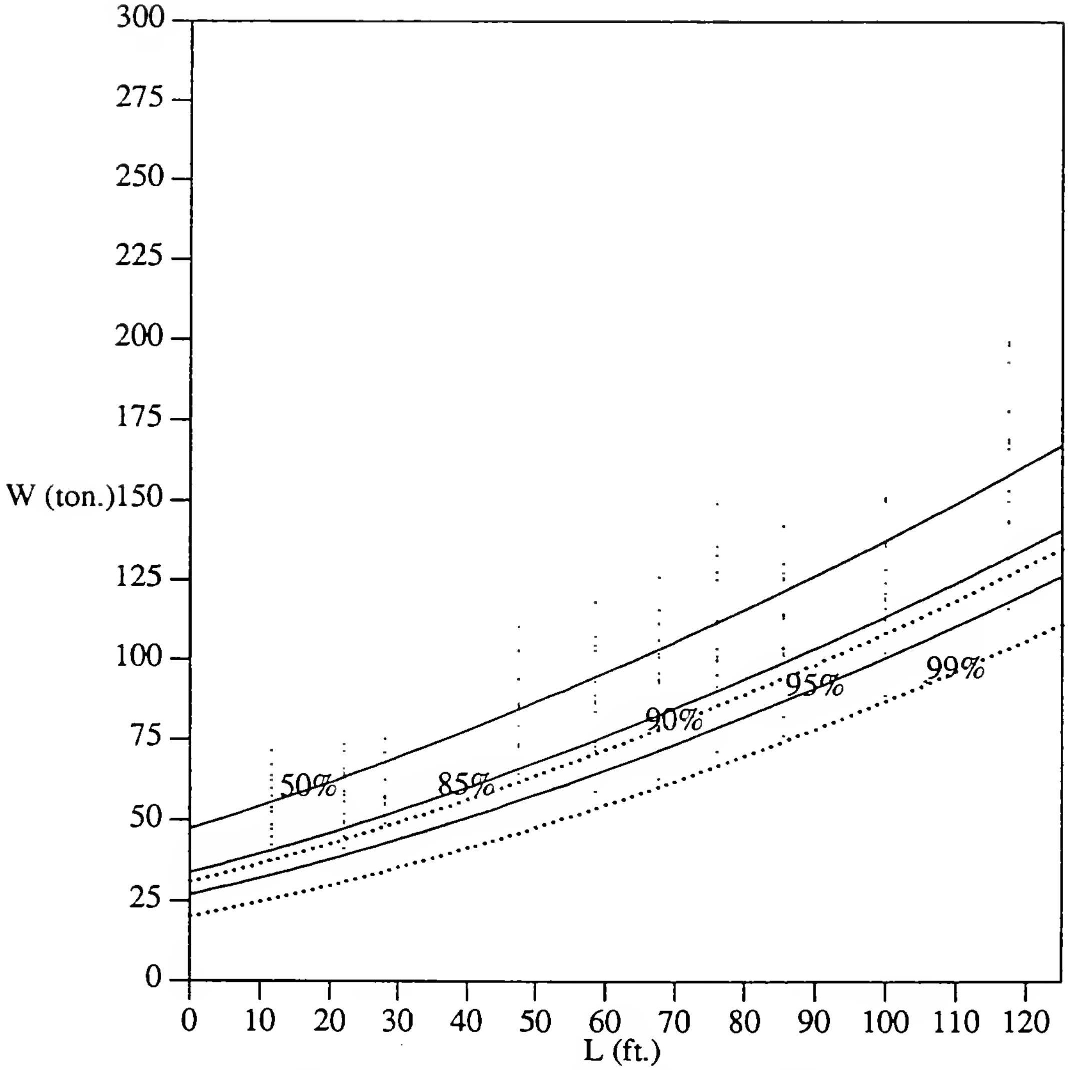


Figure 4.6 Allowable load, W, vs. Wheel Base, L, for test sample of bridges and the predicted allowable loads at confidence levels 50%, 85%, 90%, 95%, and 99%

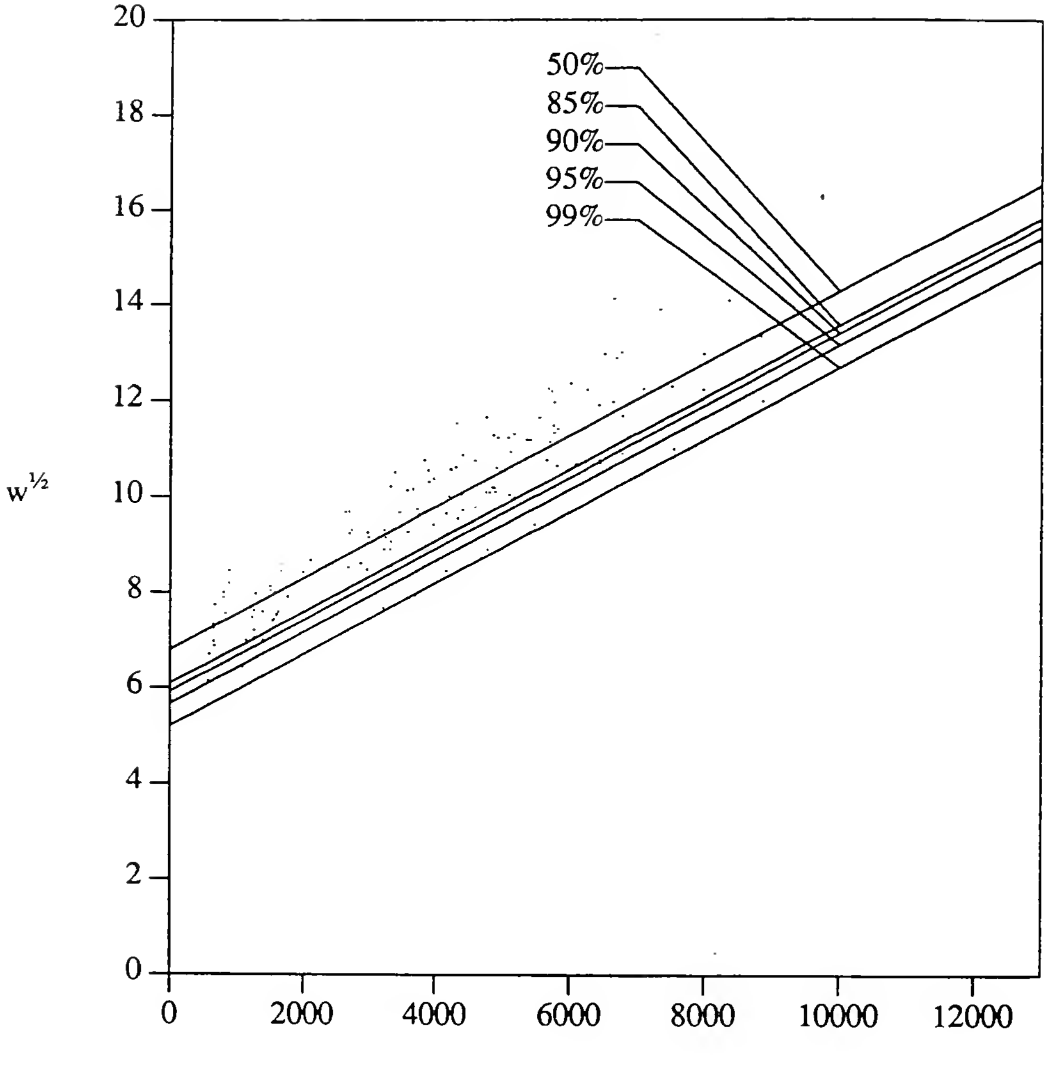


Figure 4.7 Transformed data, $w^{1/2}$, vs. the product of HS truck capacity and Wheel Base, L, for test sample of bridges and the predicted $w^{1/2}$ at confidence levels 50%, 85%, 90%, 95%, and 99%

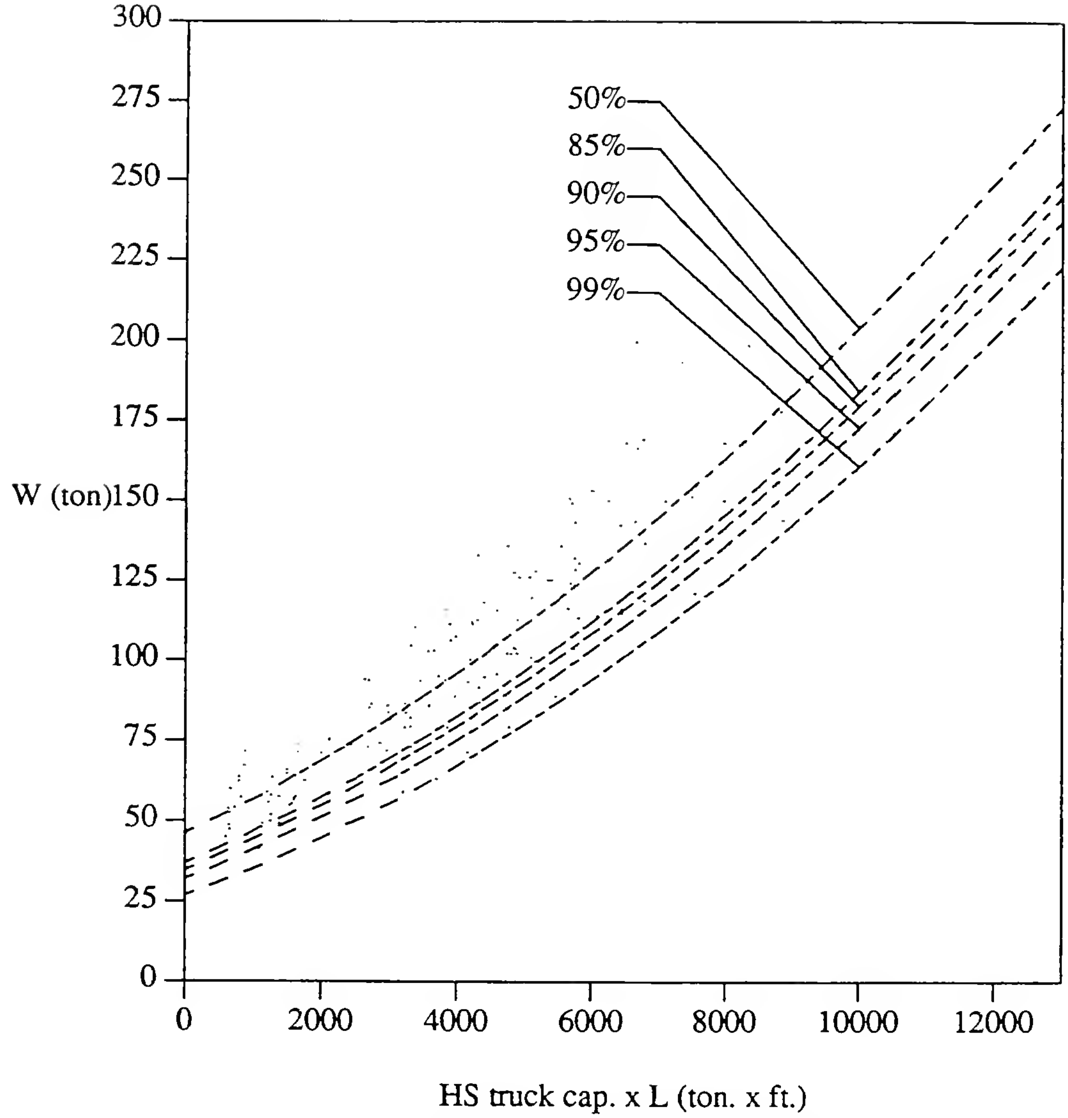


Figure 4.8 Allowable load, W, vs. the product of HS truck capacity and Wheel Base, L, for test sample of bridges and allowable load at confidence levels 50%, 85%, 90%, 95%, and 99%

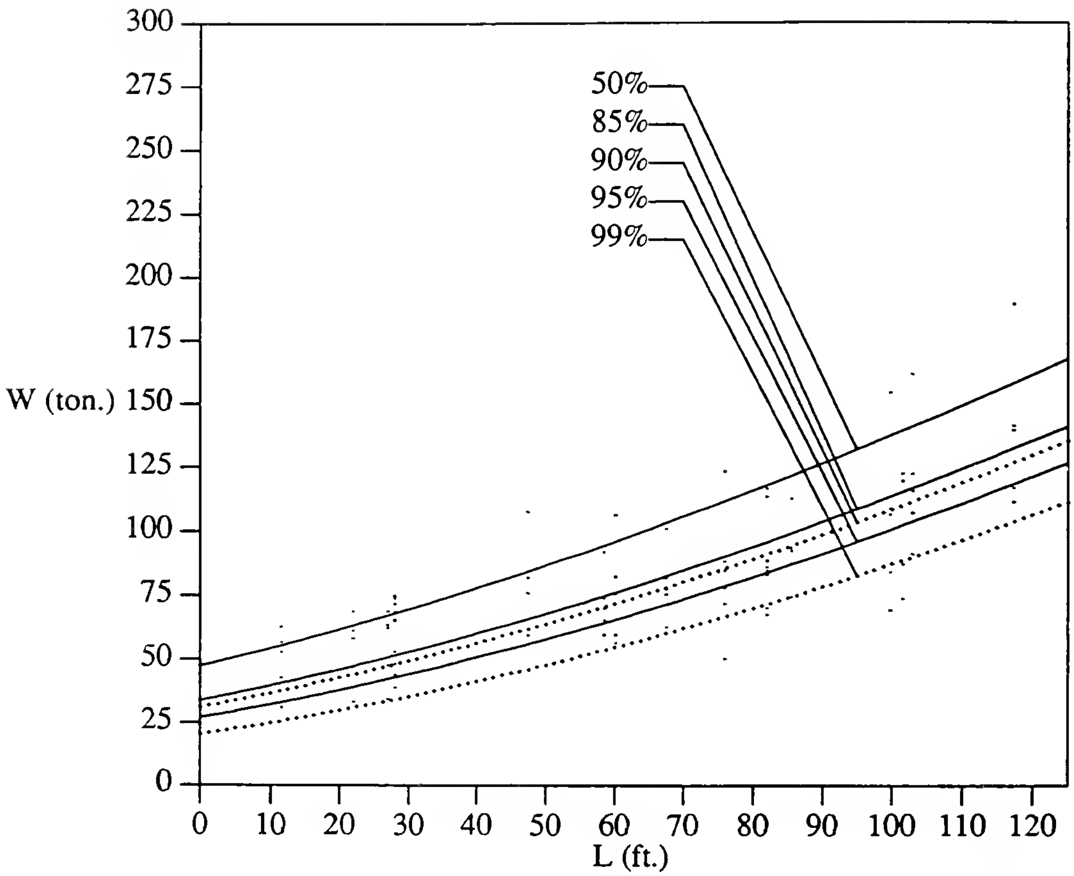


Figure 4.9 Allowable load, W, vs. the wheel base, L, for cpcbb bridges and the confidence limits for all bridges

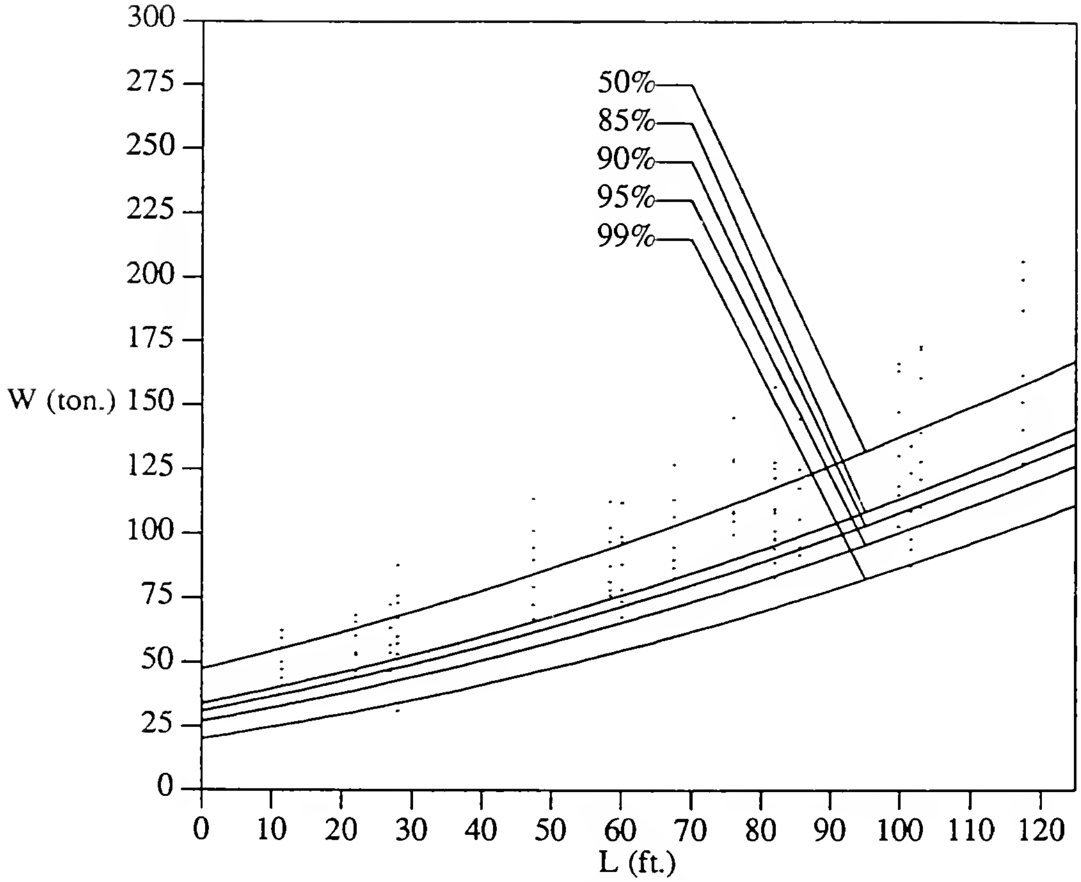


Figure 4.10 Allowable load, W, vs. the wheel base, L, for cpcib bridges and the confidence limits for all bridges

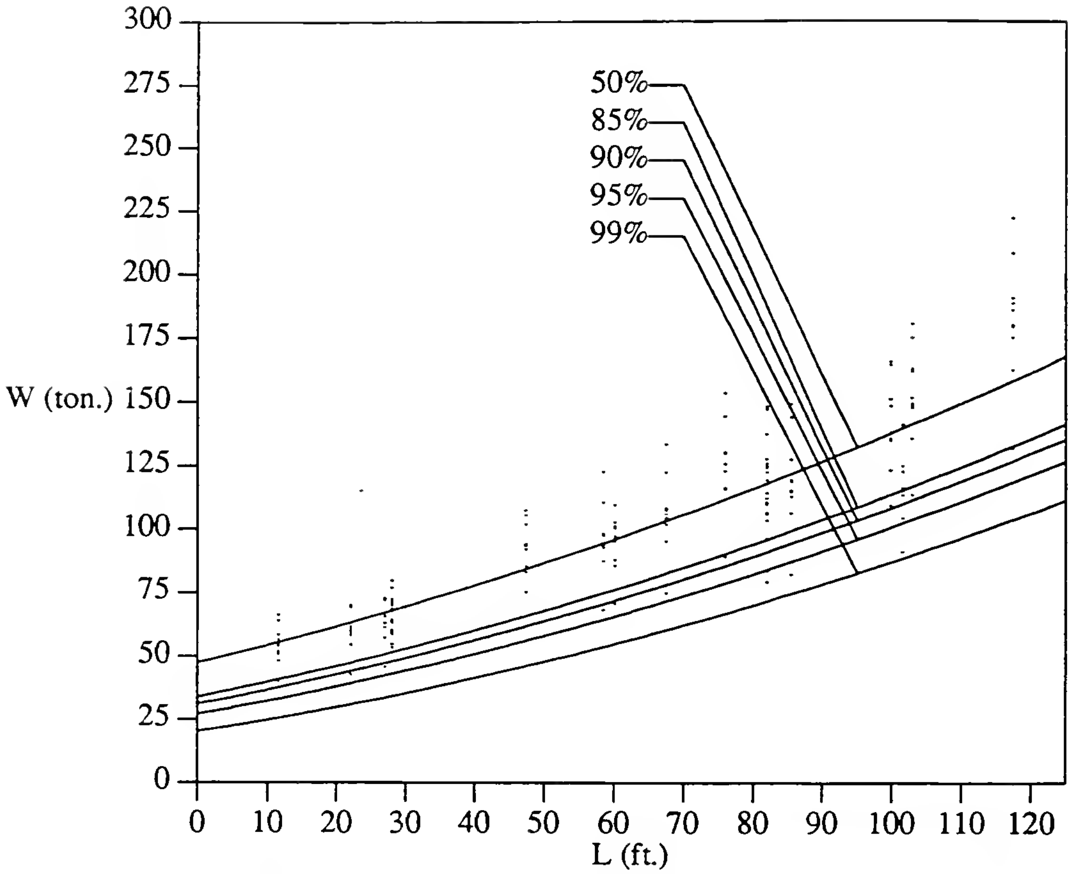


Figure 4.11 Allowable load, W, vs. the wheel base, L, for crcg bridges and the confidence limits for all the bridges

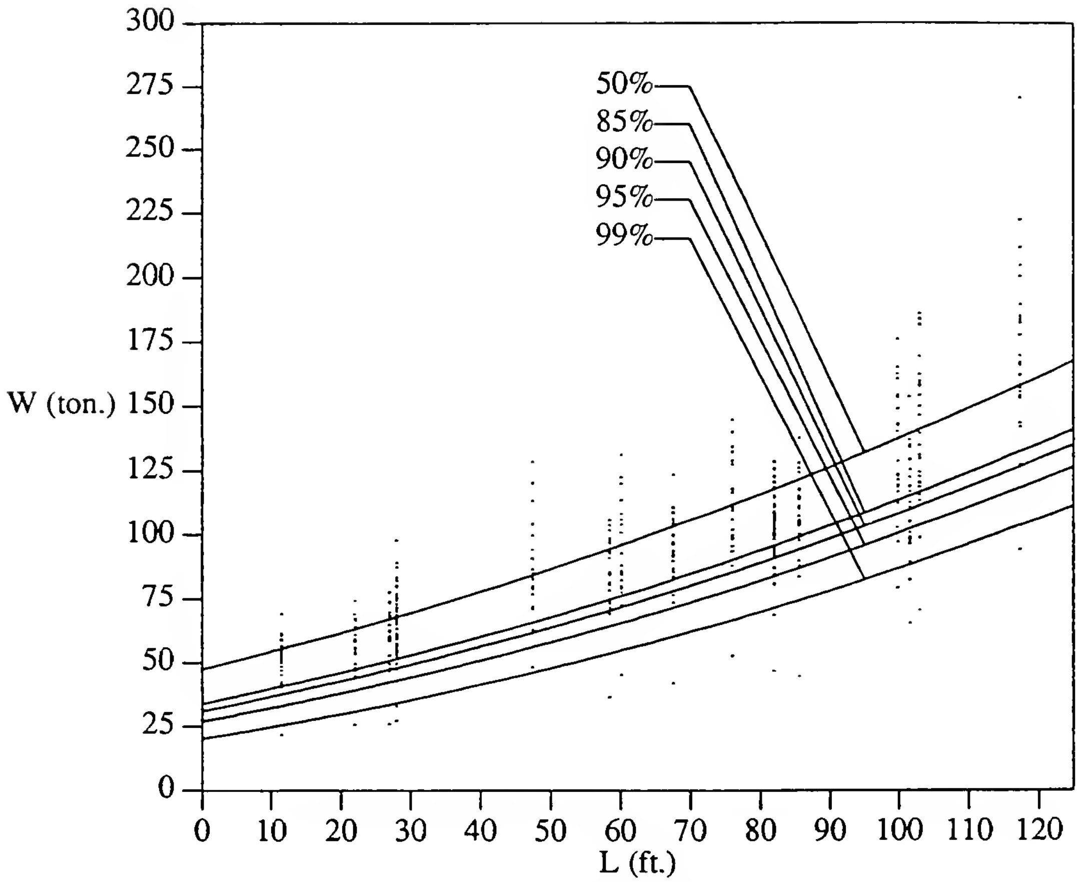


Figure 4.12 Allowable load, W, vs. the wheel base, L, for crcs bridges and the confidence limits for all the bridges

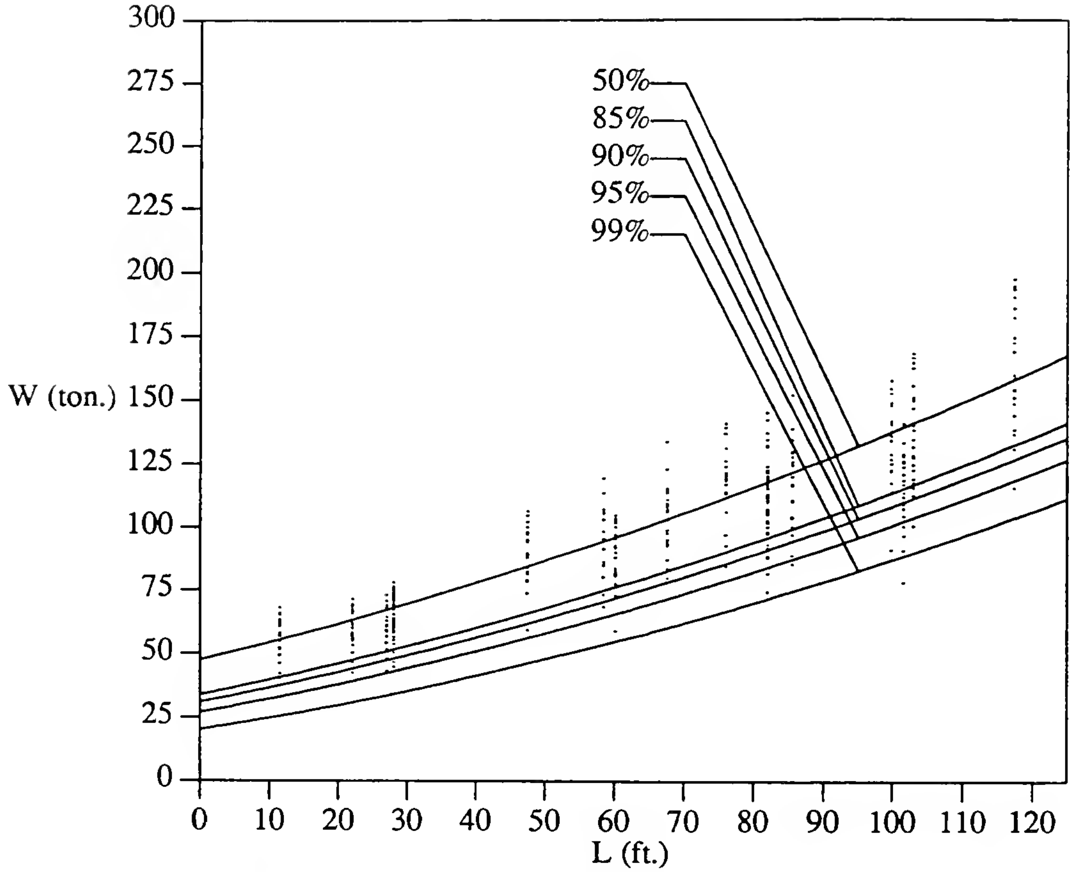


Figure 4.13 Allowable load, W, vs. the wheel base, L, for csb bridges and the confidence limits for all the bridges

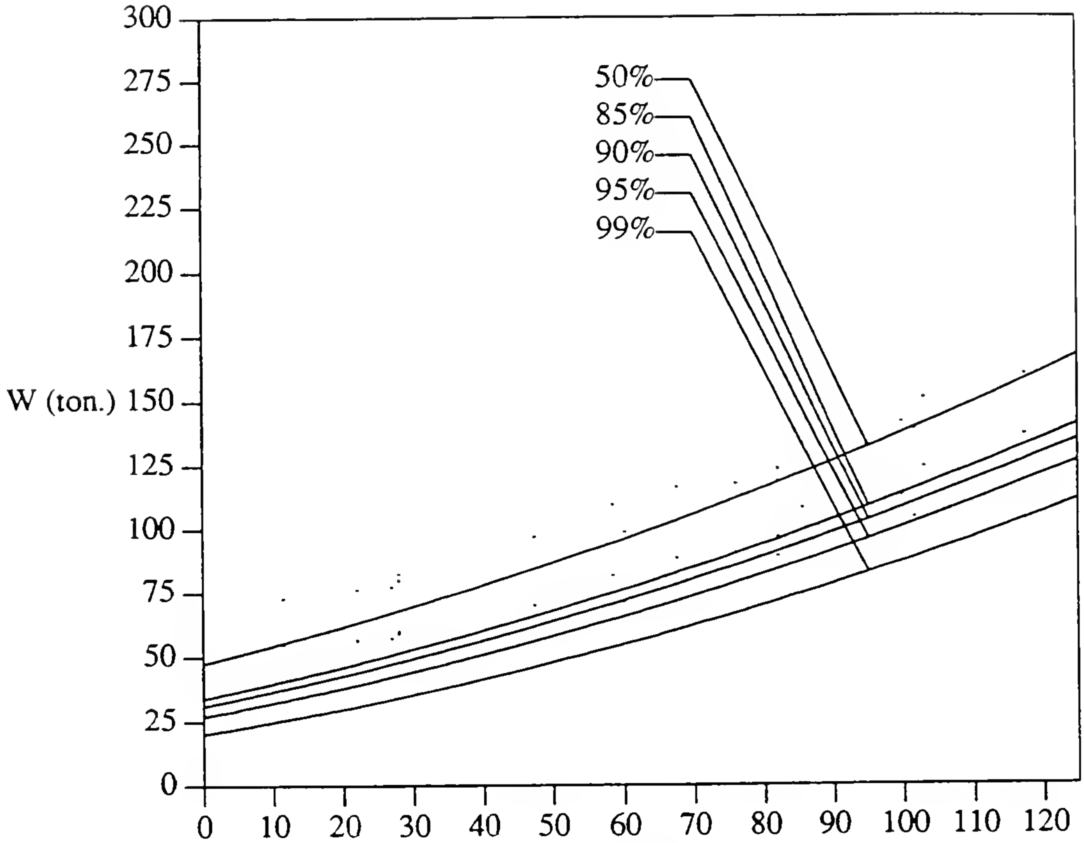


Figure 4.14 Allowable load, W, vs. the wheel base, L, for csg bridges and the confidence limits for all the bridges

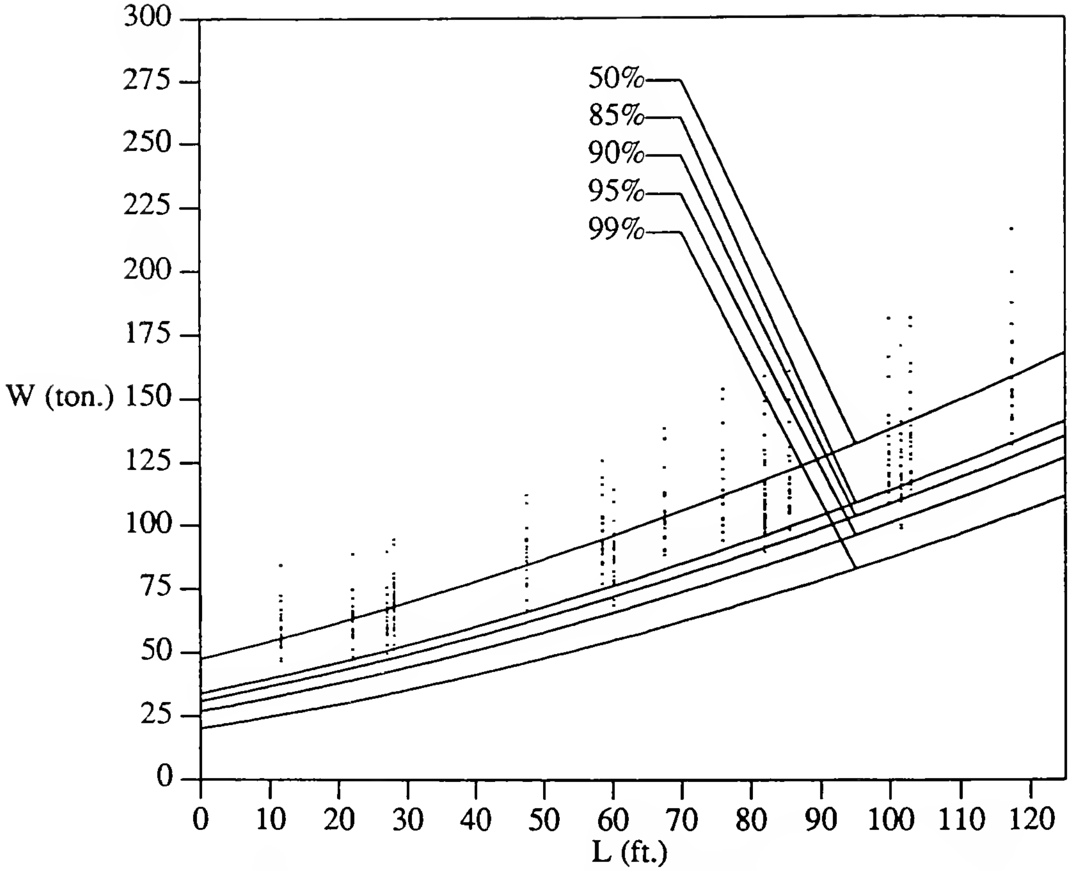


Figure 4.15 Allowable load, W, vs. the wheel base, L, for kcsb bridges and the confidence limits for all the bridges

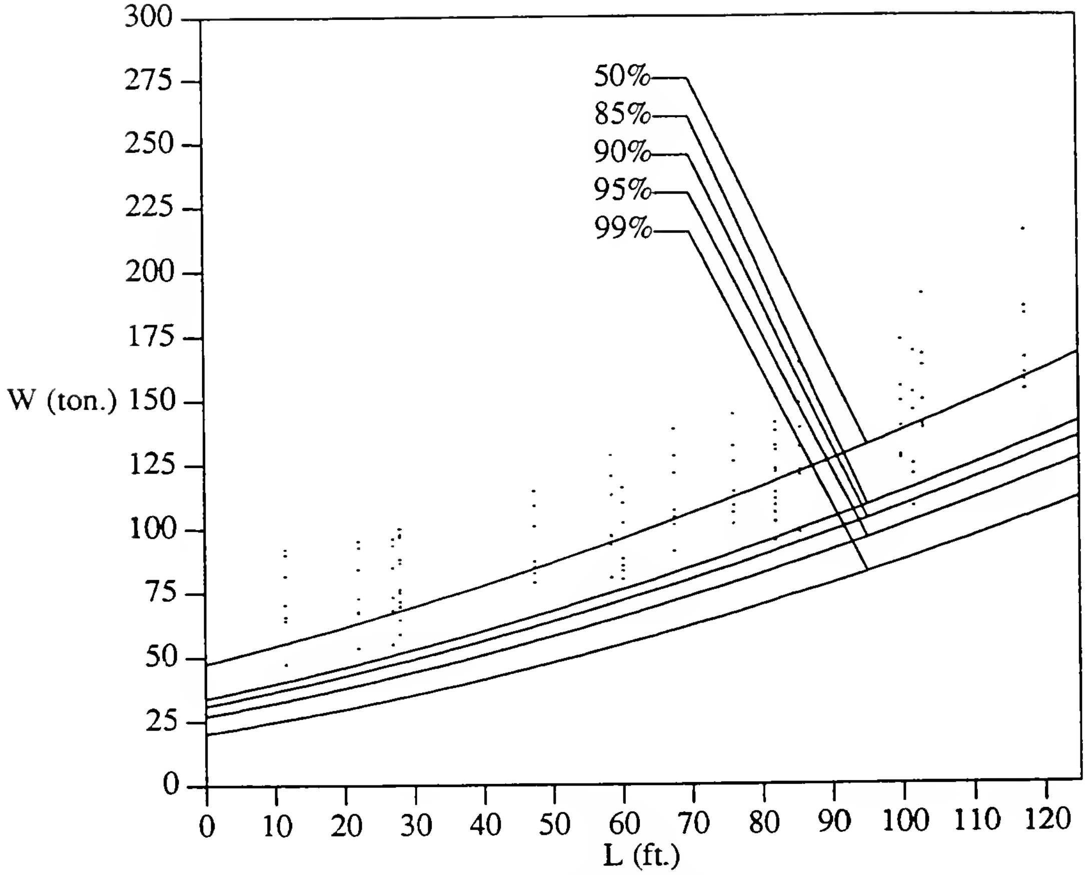


Figure 4.16 Allowable load, W, vs. the wheel base, L, for kcsg bridges and the confidence limits for all the bridges

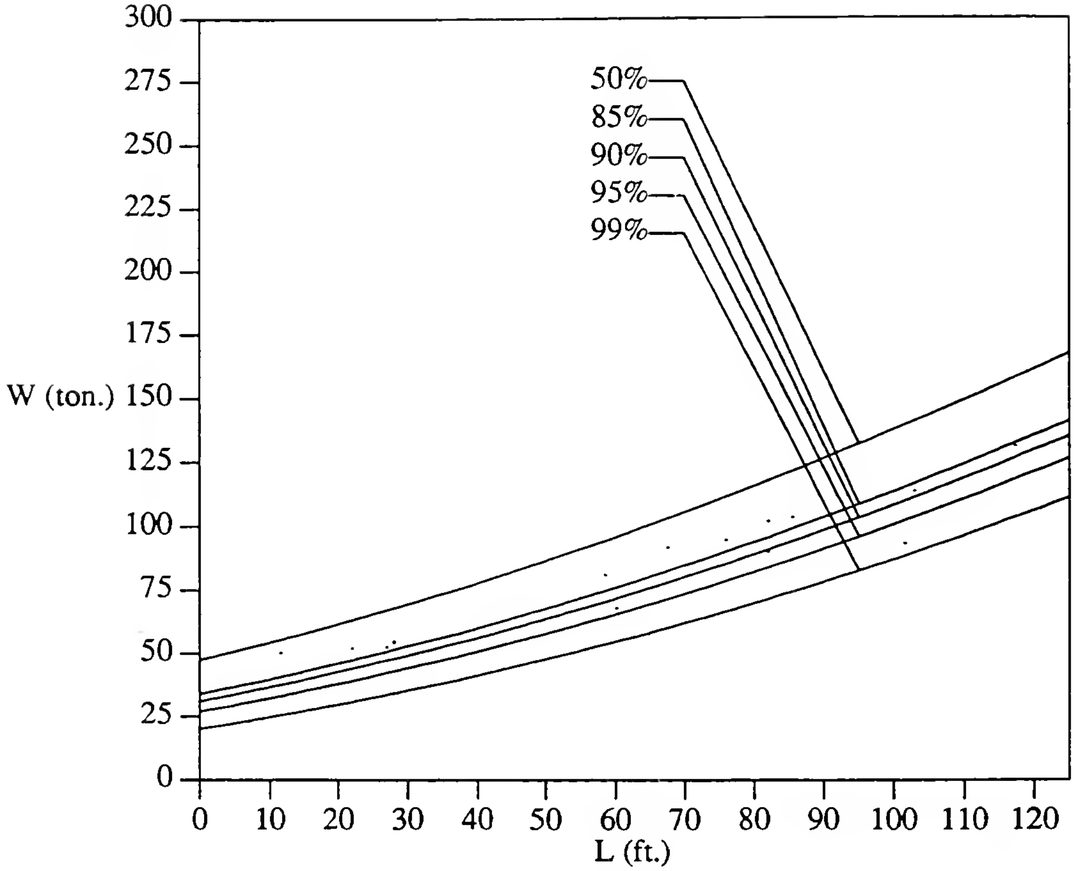


Figure 4.17 Allowable load, W, vs. the wheel base, L, for ksb bridges and the confidence limits for all the bridges

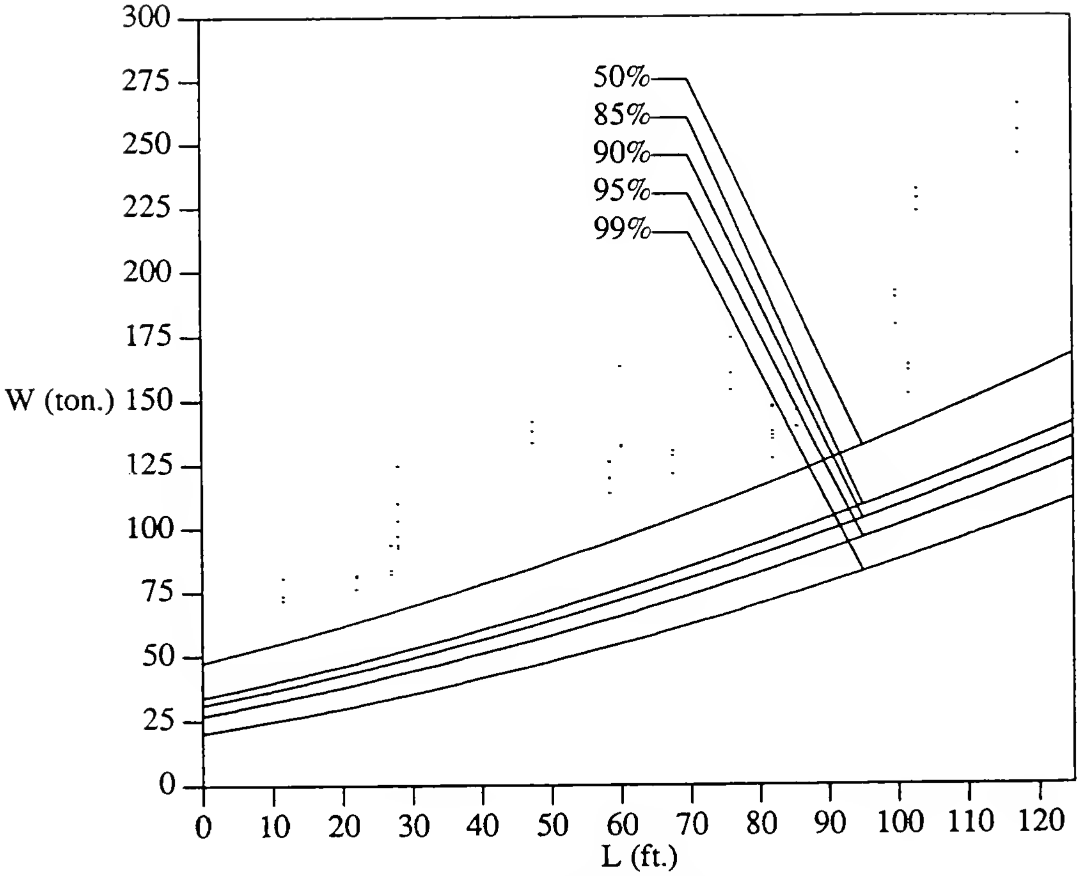


Figure 4.18 Allowable load, W, vs. the wheel base, L, for pcb bridges and the confidence limits for all the bridges

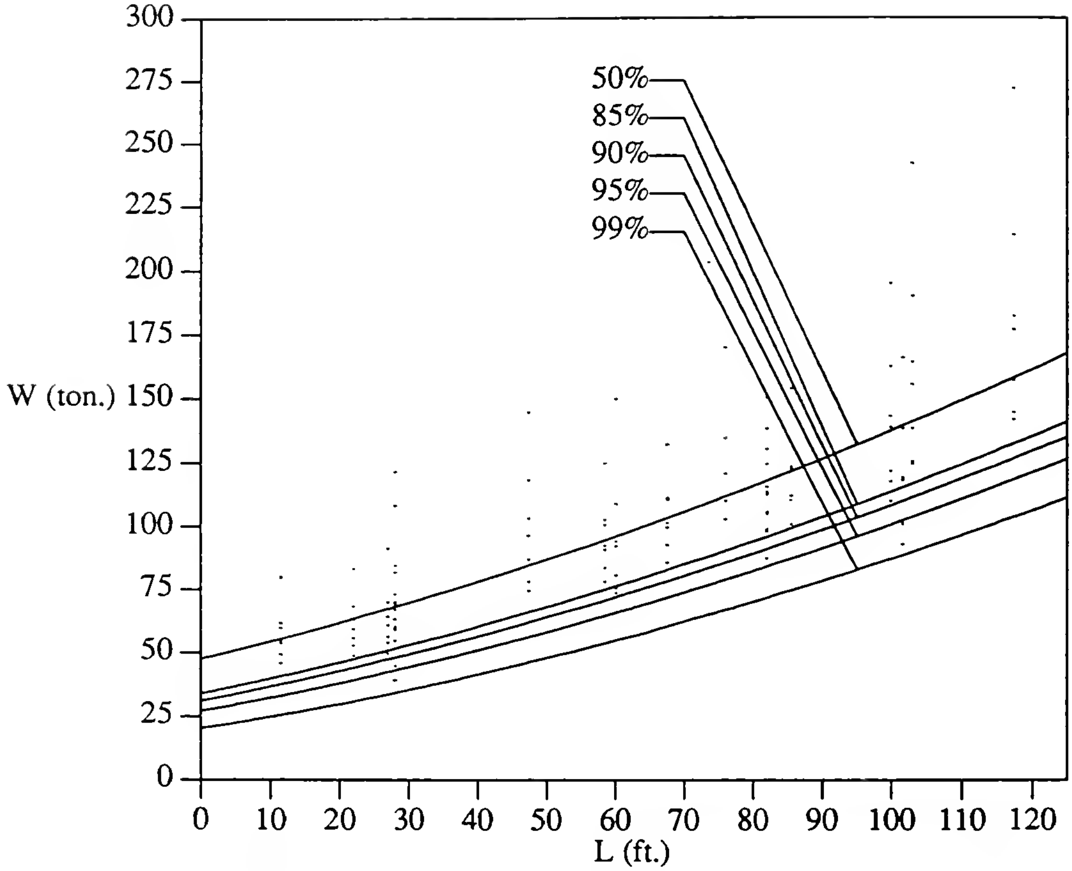


Figure 4.19 Allowable load, W, vs. the wheel base, L, for pcbb bridges and the confidence limits for all the bridges

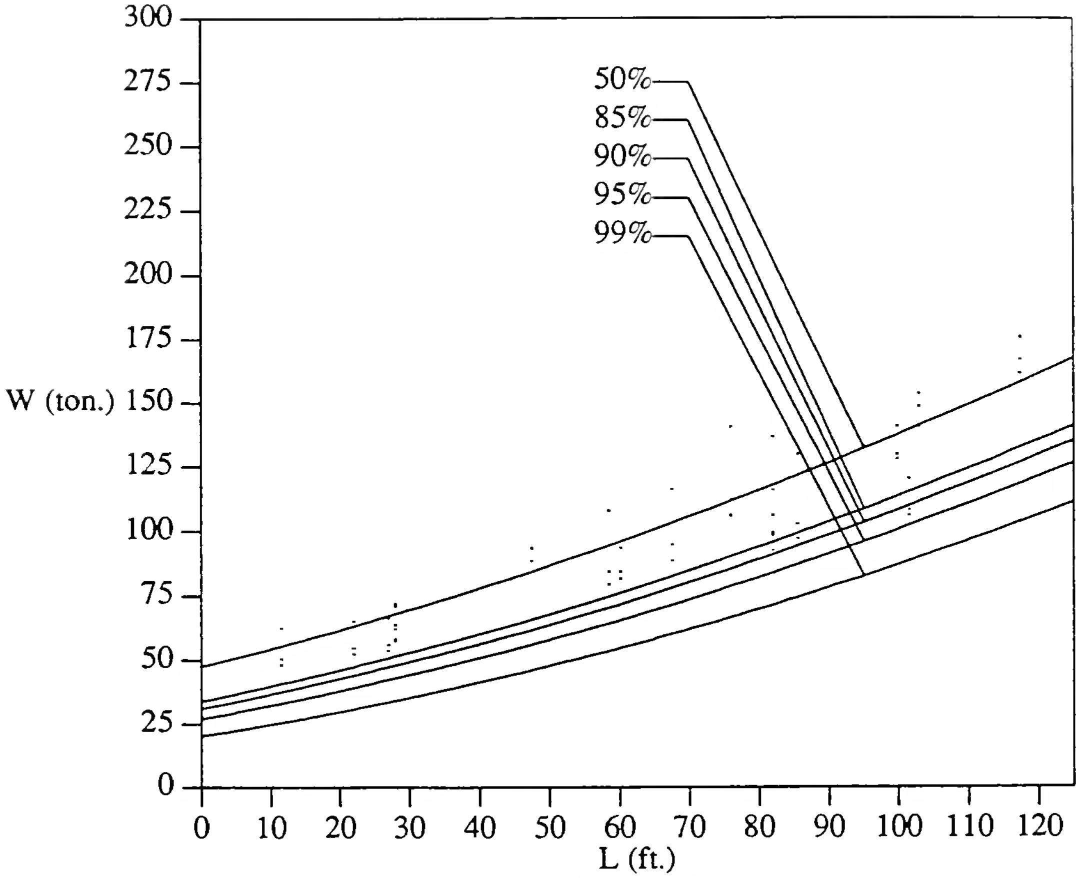


Figure 4.20 Allowable load, W, vs. the wheel base, L, for pcib bridges and the confidence limits for all the bridges

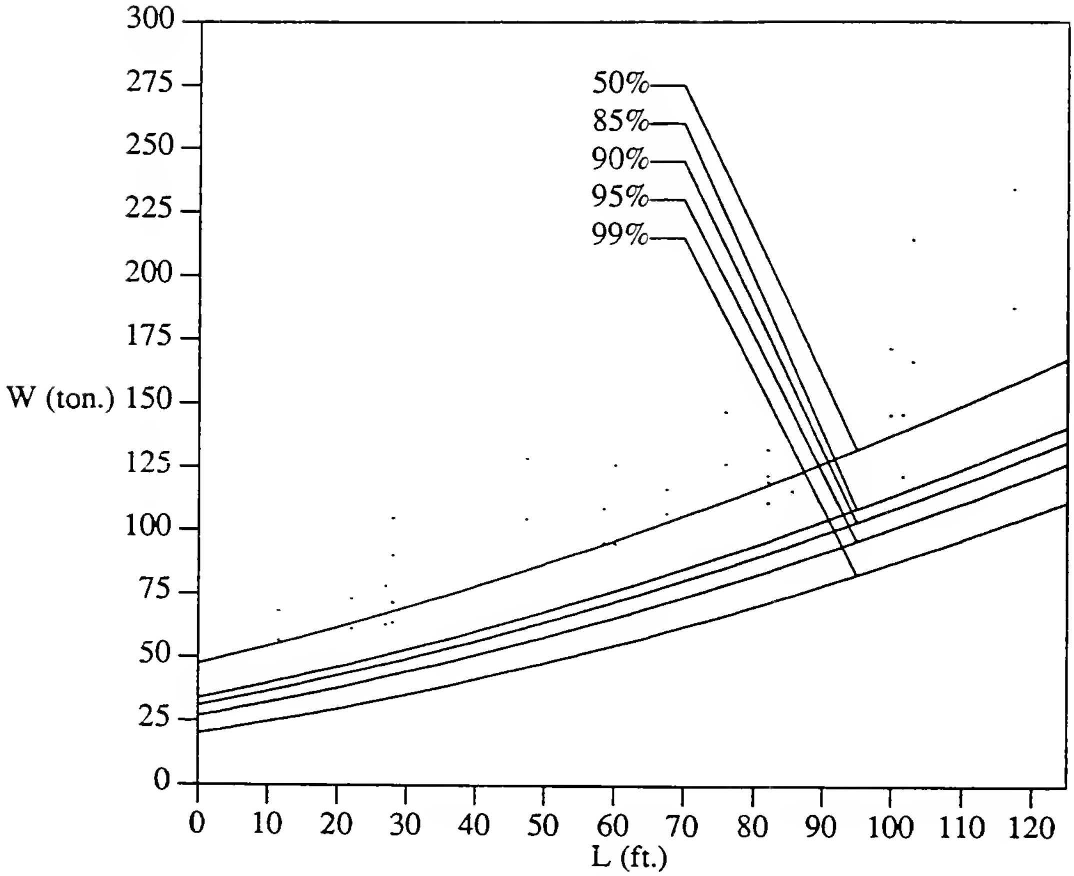


Figure 4.21 Allowable load, W, vs. the wheel base, L, for rca bridges and the confidence limits for all the bridges

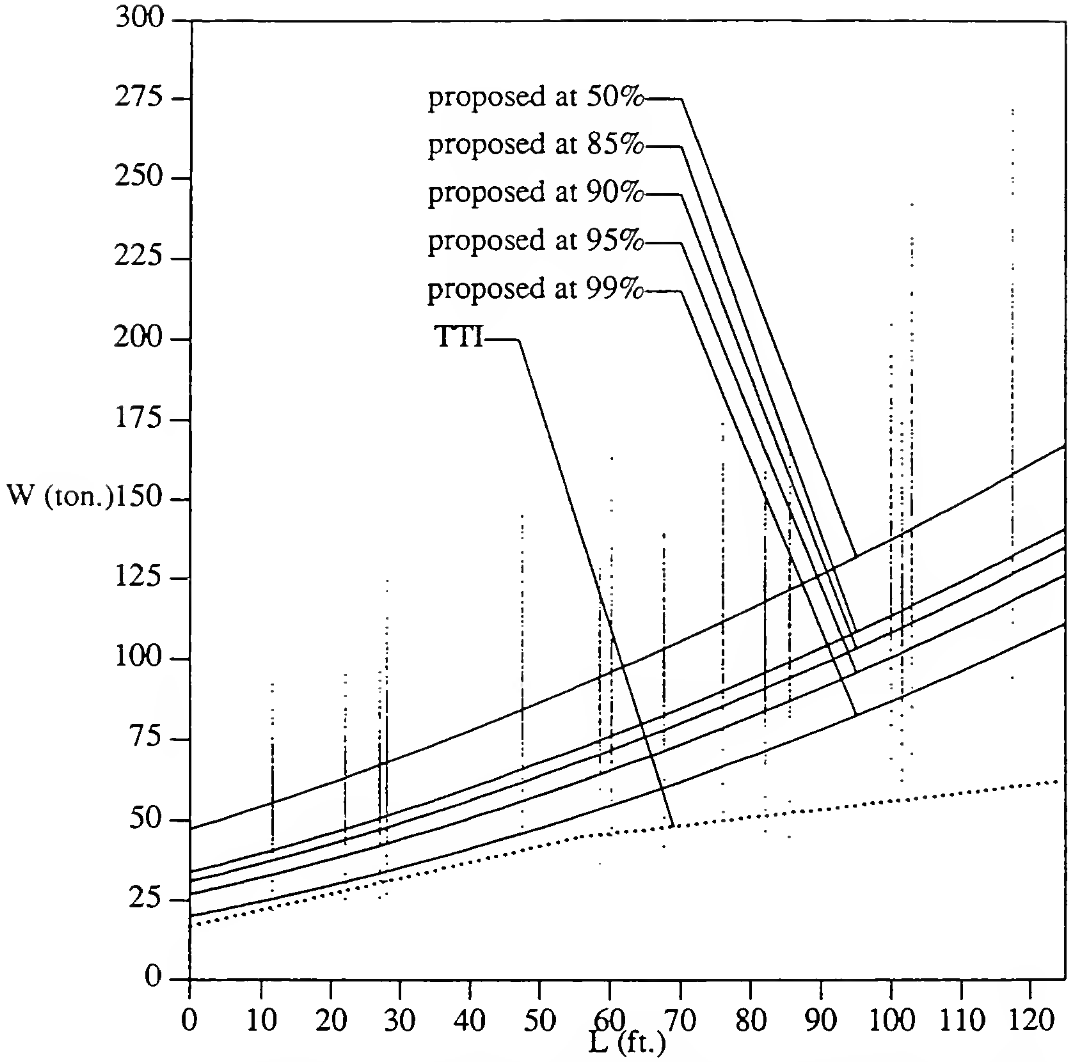


Figure 4.60 Allowable load, W, vs. wheel base, L, for 10 ≤ L ≤ 120 ft. superimposed on the proposed confidence limits at operating stress level (i.e 36% overstress beyond design stress level) and that by Noel and James (1989) at only 5% overstress for HS20 designed bridges and 30% overstress for H15 designed bridges beyond design stress level

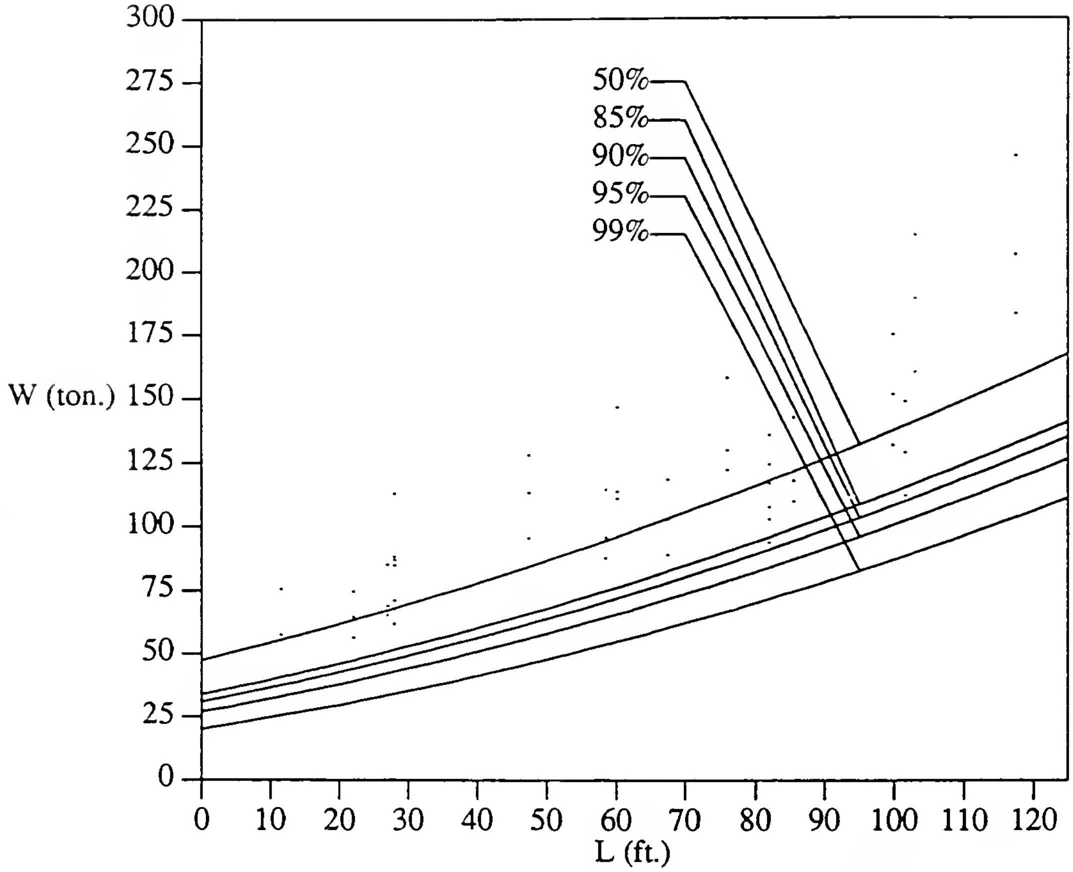


Figure 4.23 Allowable load, W, vs. the wheel base, L, for rcs bridges and the confidence limits for all the bridges

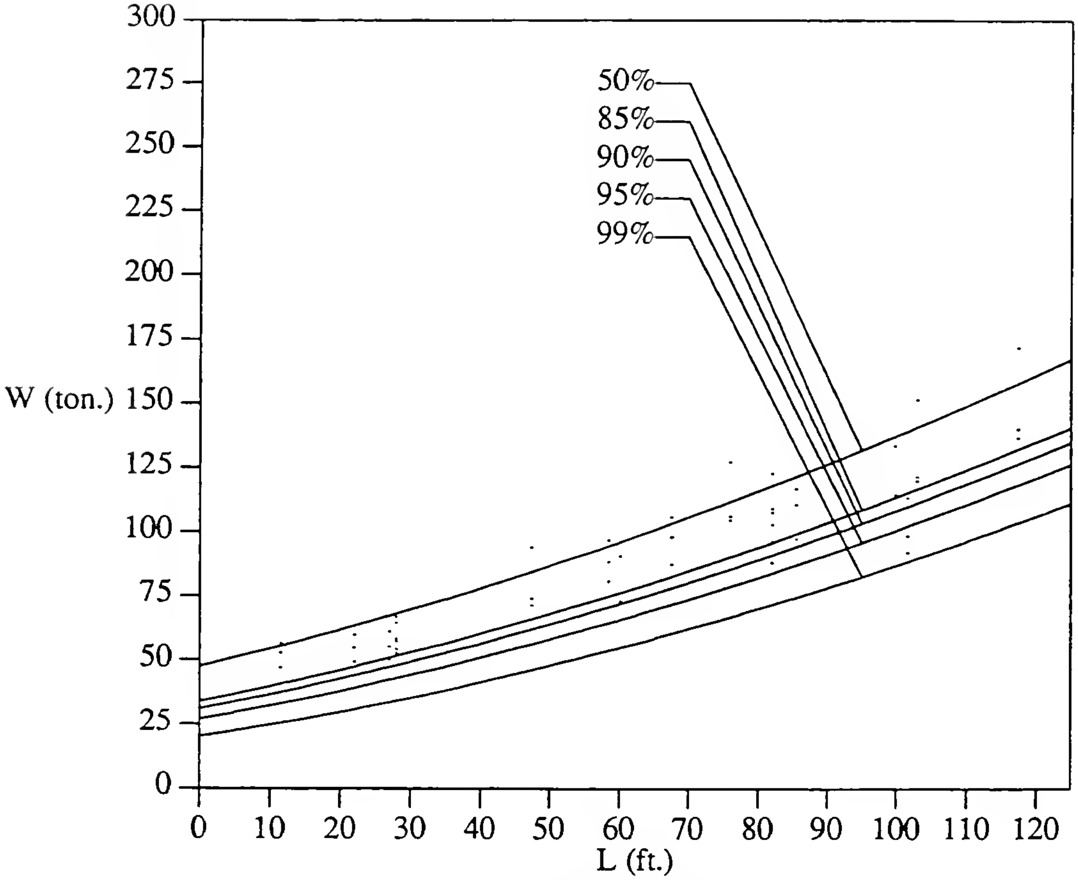


Figure 4.24 Allowable load, W, vs. the wheel base, L, for sb bridges and the confidence limits for all the bridges

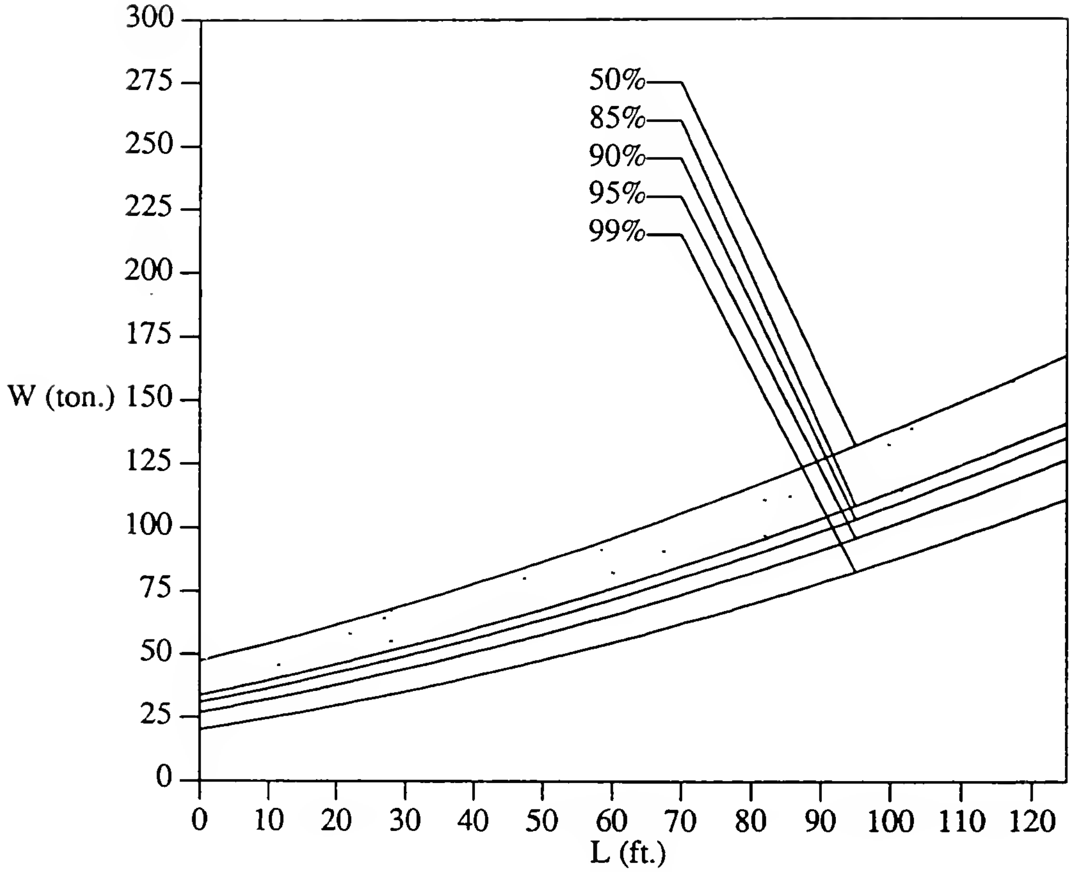


Figure 4.25 Allowable load, W, vs. the wheel base, L, for sg bridges and the confidence limits for all the bridges

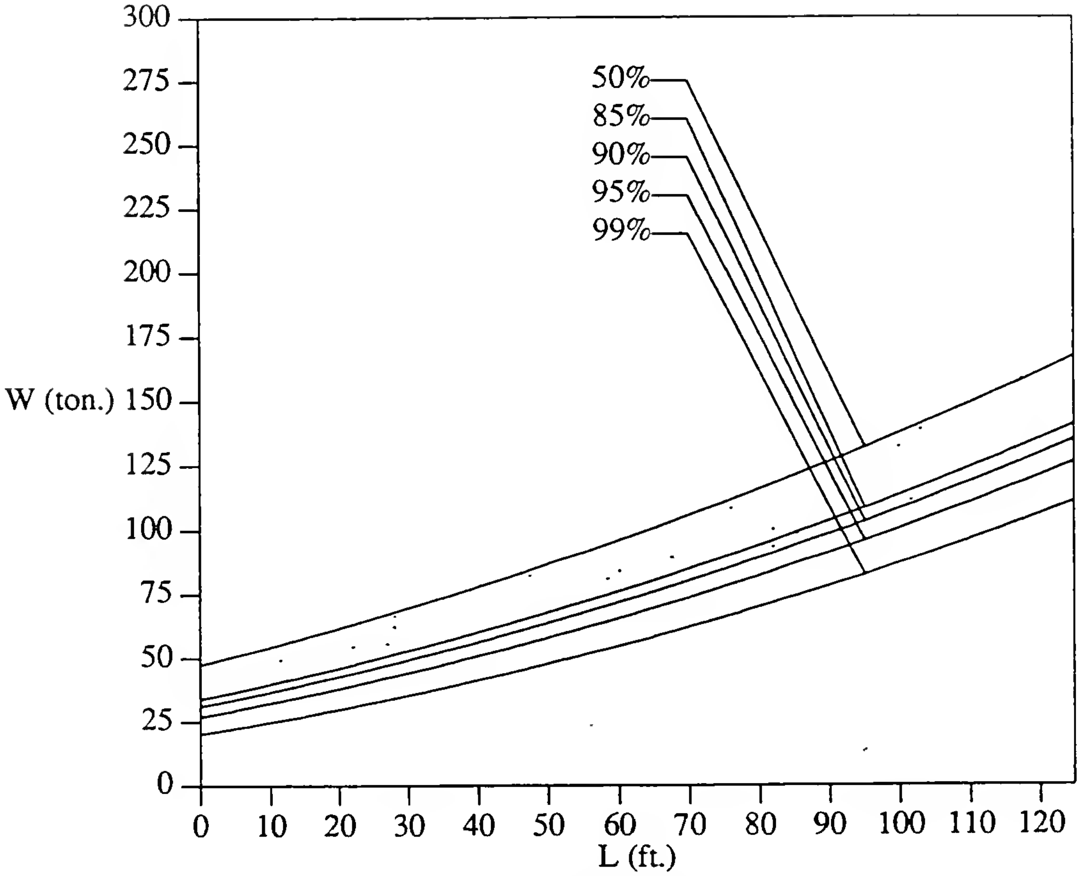


Figure 4.26 Allowable load, W, vs. the wheel base, L, for spt bridges and the confidence limits for all the bridges

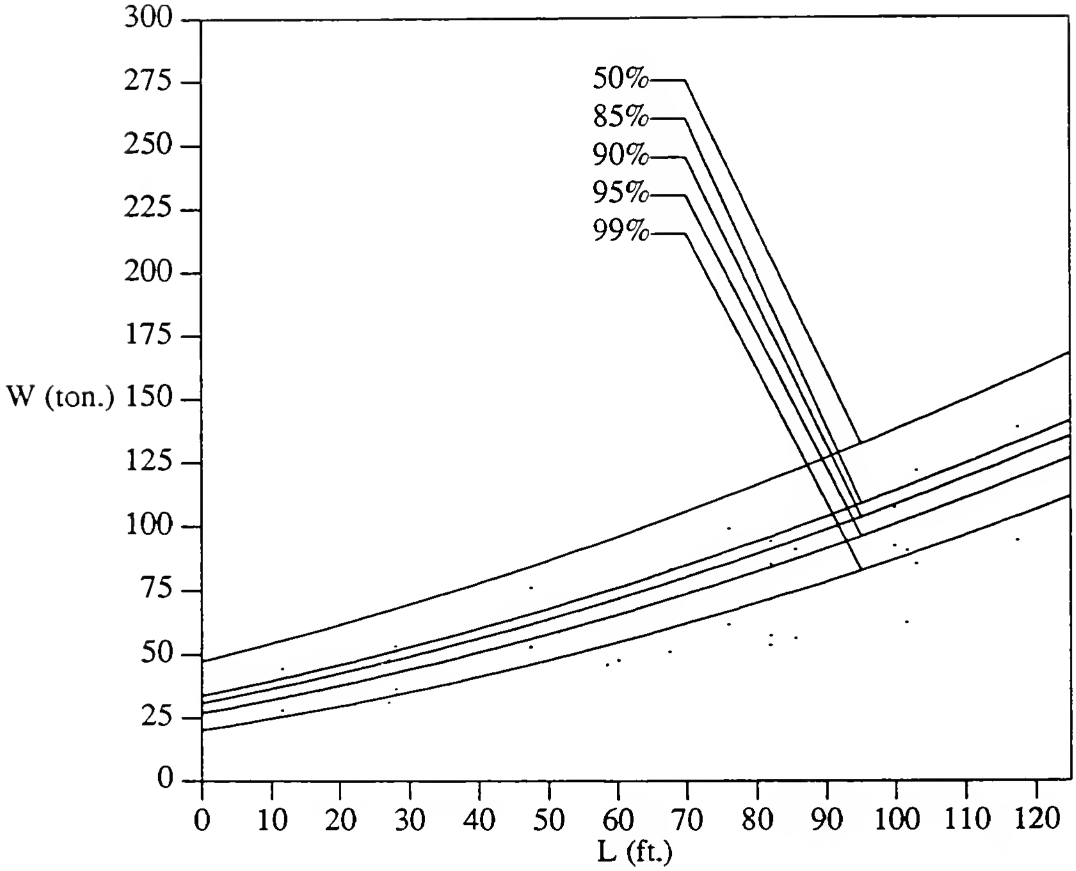


Figure 4.27 Allowable load, W, vs. the wheel base, L, for stt bridges and the confidence limits for all the bridges

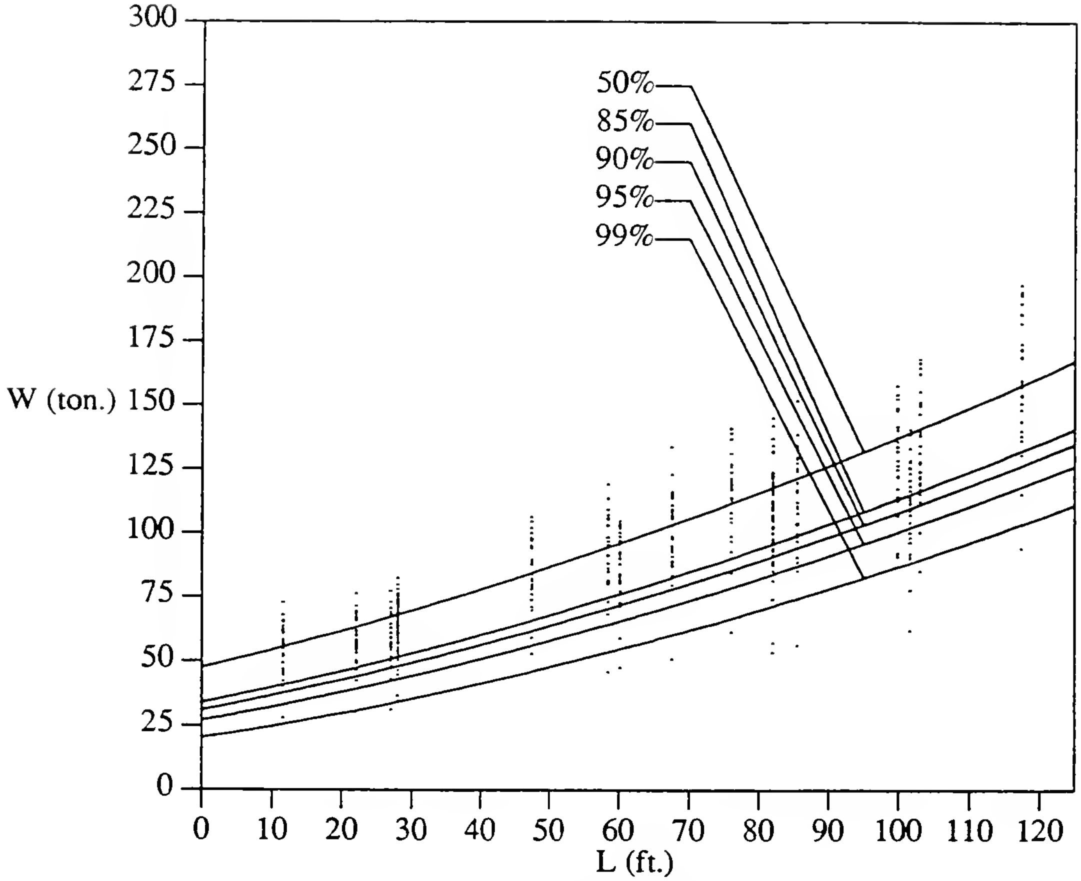


Figure 4.28 Allowable load, W, vs. wheel base, L, for SS type bridges and the confidence limits for all bridges

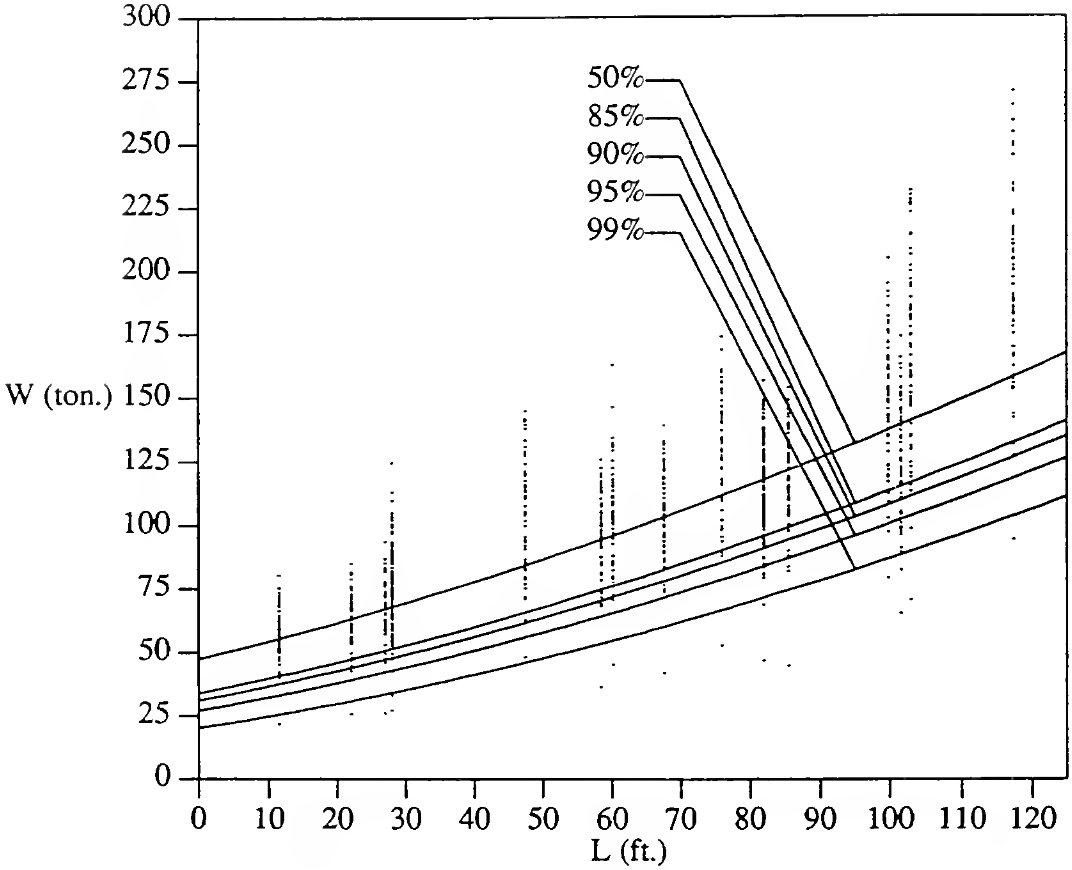


Figure 4.29 Allowable load, W, vs. wheel base, L, for RC type bridges and the confidence limits for all bridges

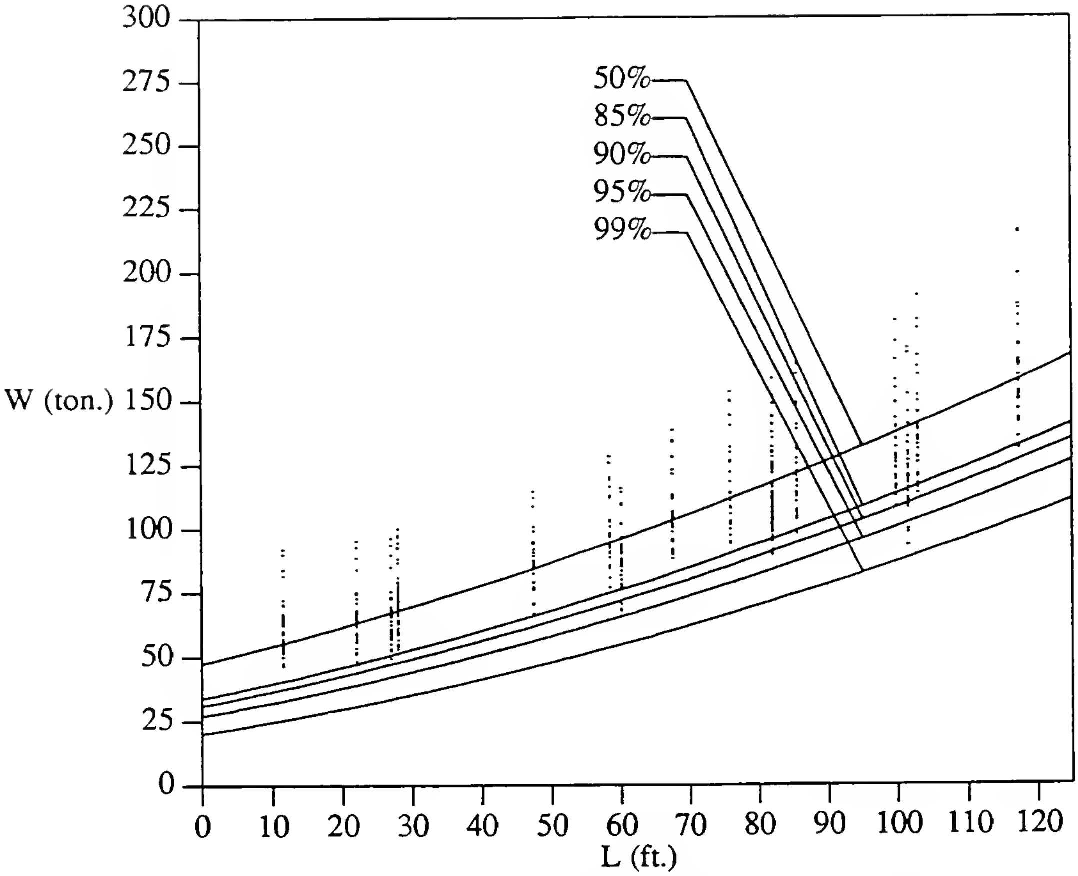


Figure 4.30 Allowable load, W, vs. wheel base, L, for CSC type bridges and the confidence limits for all bridges

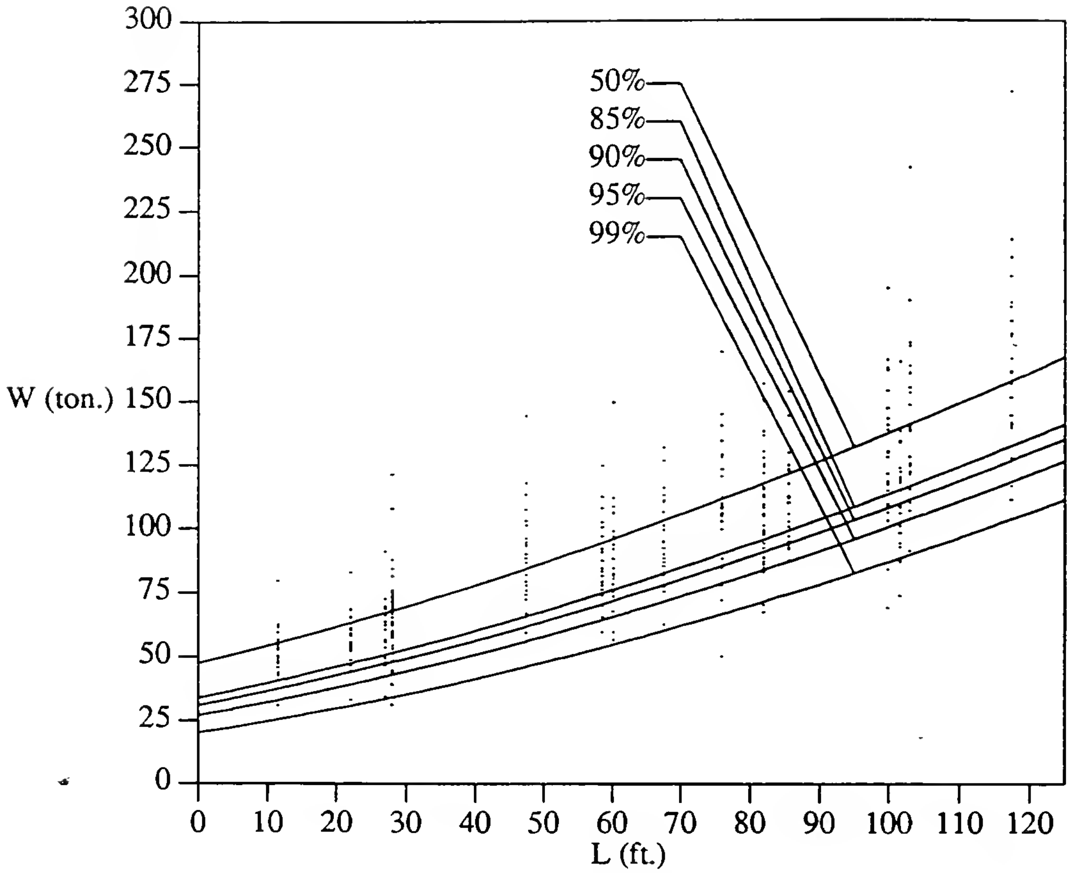


Figure 4.31 Allowable load, W, vs. wheel base, L, for PSC & CPS type bridges and the confidence limits for all bridges

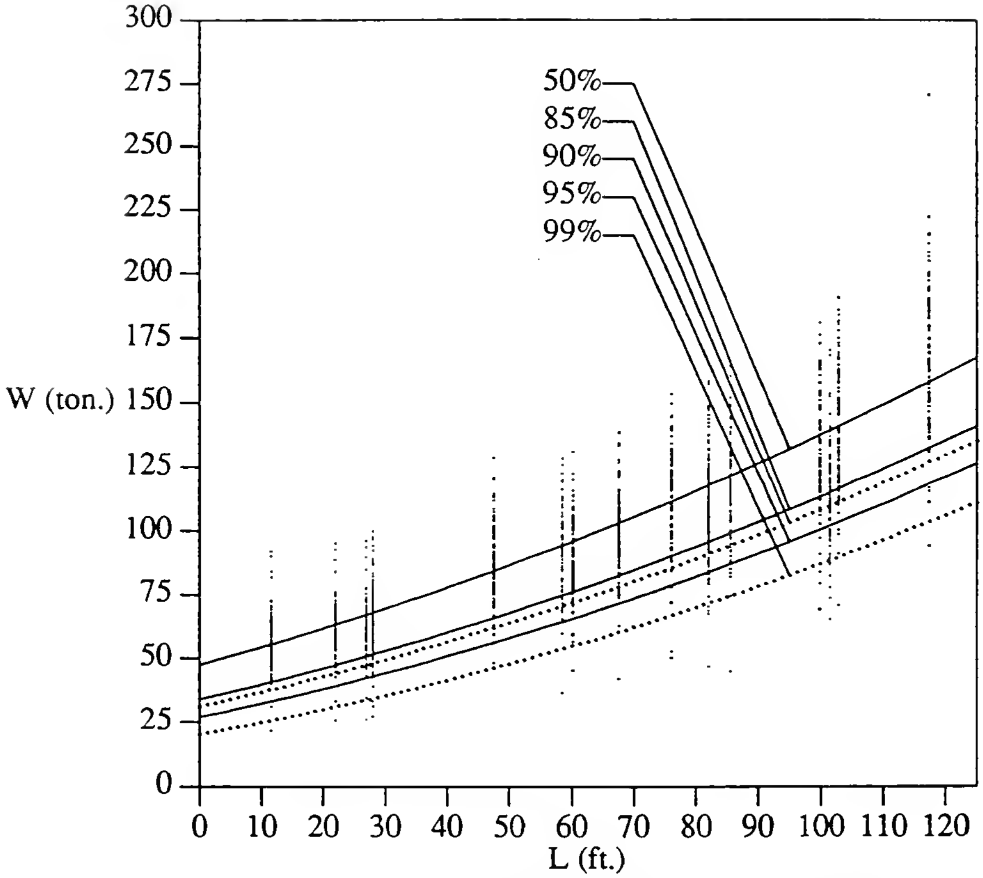


Figure 4.32 Allowable load, W, vs. the wheel base, L, for continuous bridges and for $10 \leq L \leq 120$ ft.

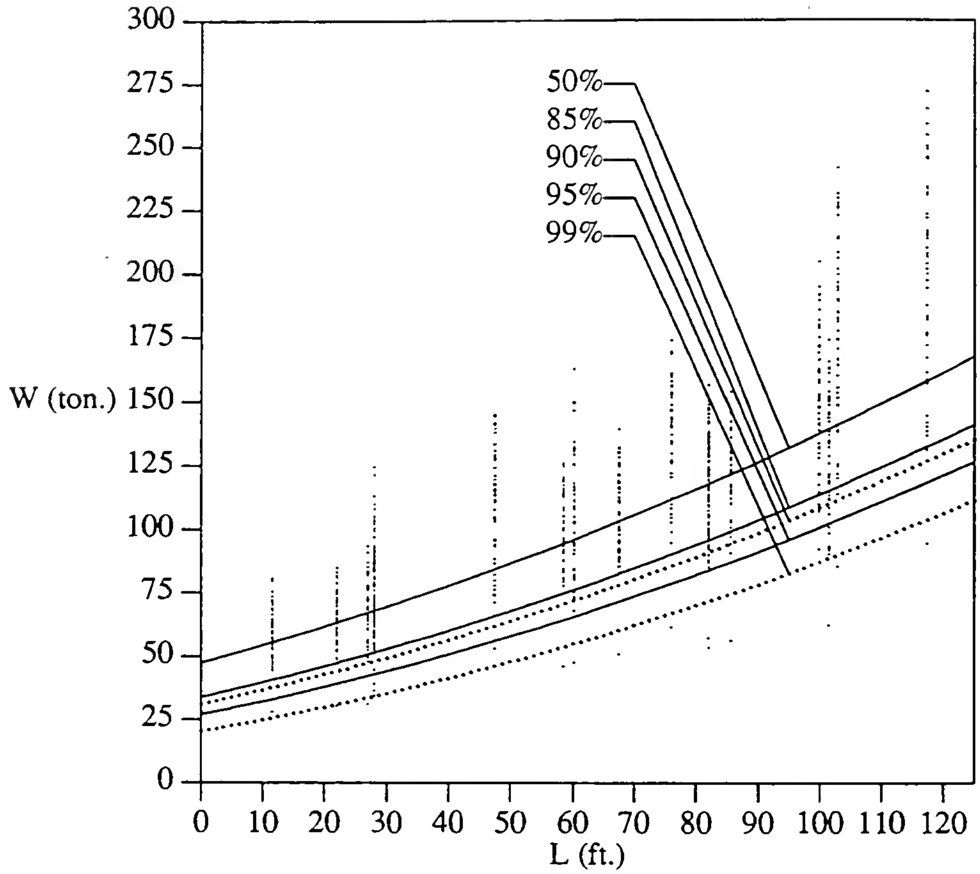


Figure 4.33 Allowable load, W, vs. the wheel base, L,
for simple span bridges and for 10 ≤ L ≤ 120 ft.

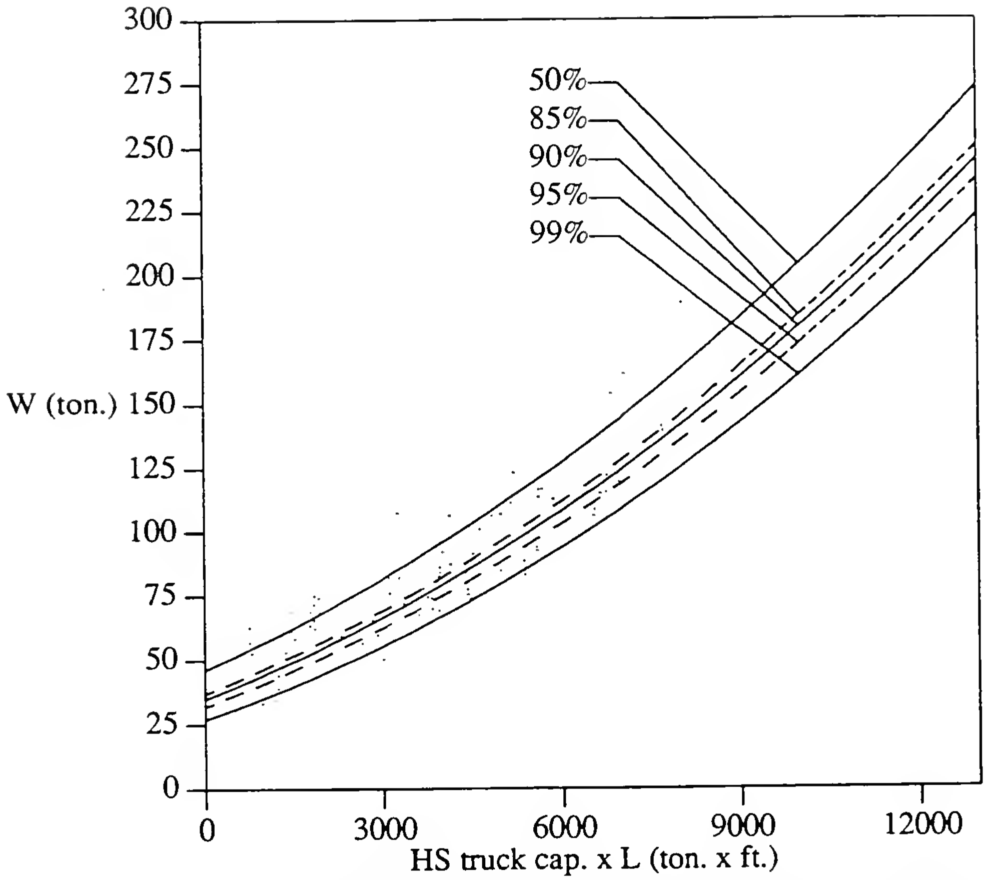


Figure 4.34 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for cpcbb bridges and for $10 \leq L \leq 120$ ft.

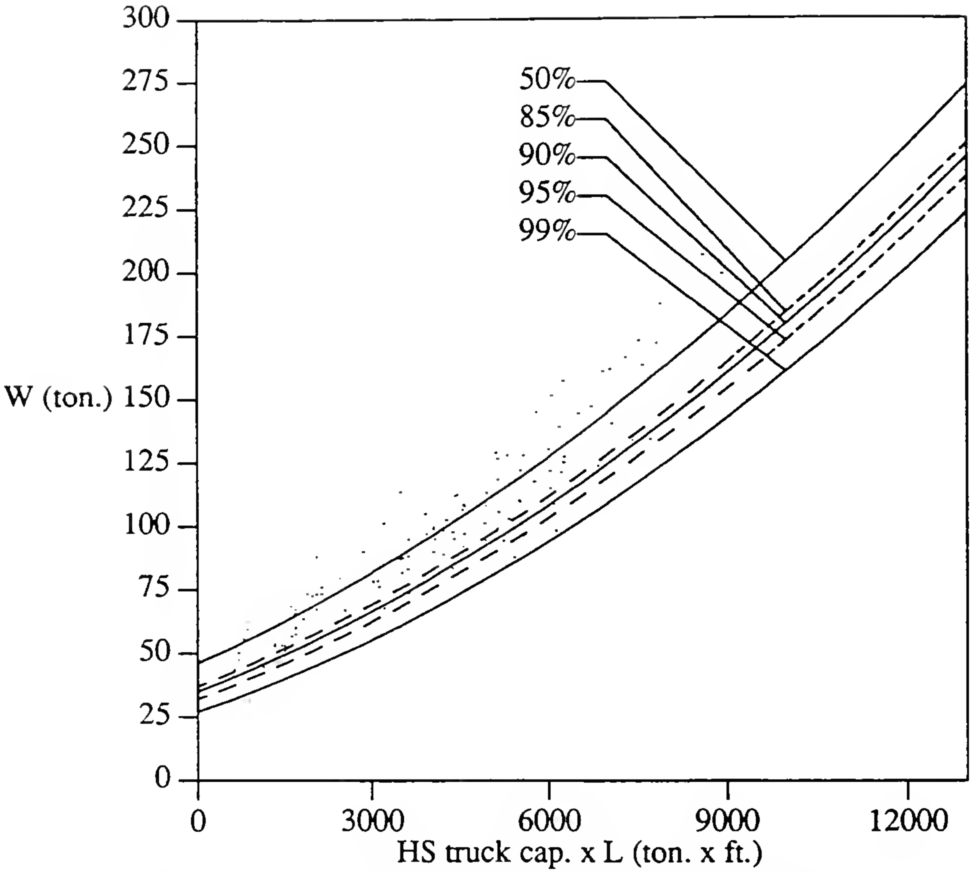


Figure 4.35 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for cpcib bridges and for $10 \leq L \leq 120$ ft.

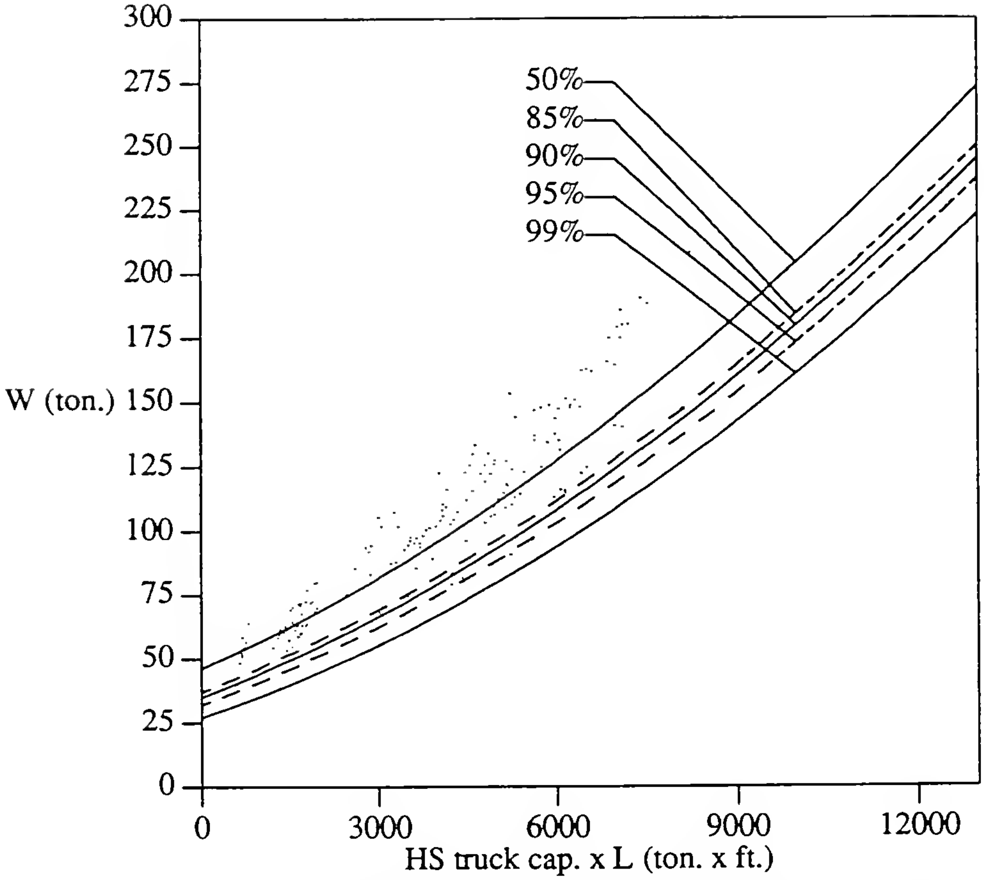


Figure 4.36 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for crcg bridges and for $10 \leq L \leq 120$ ft.

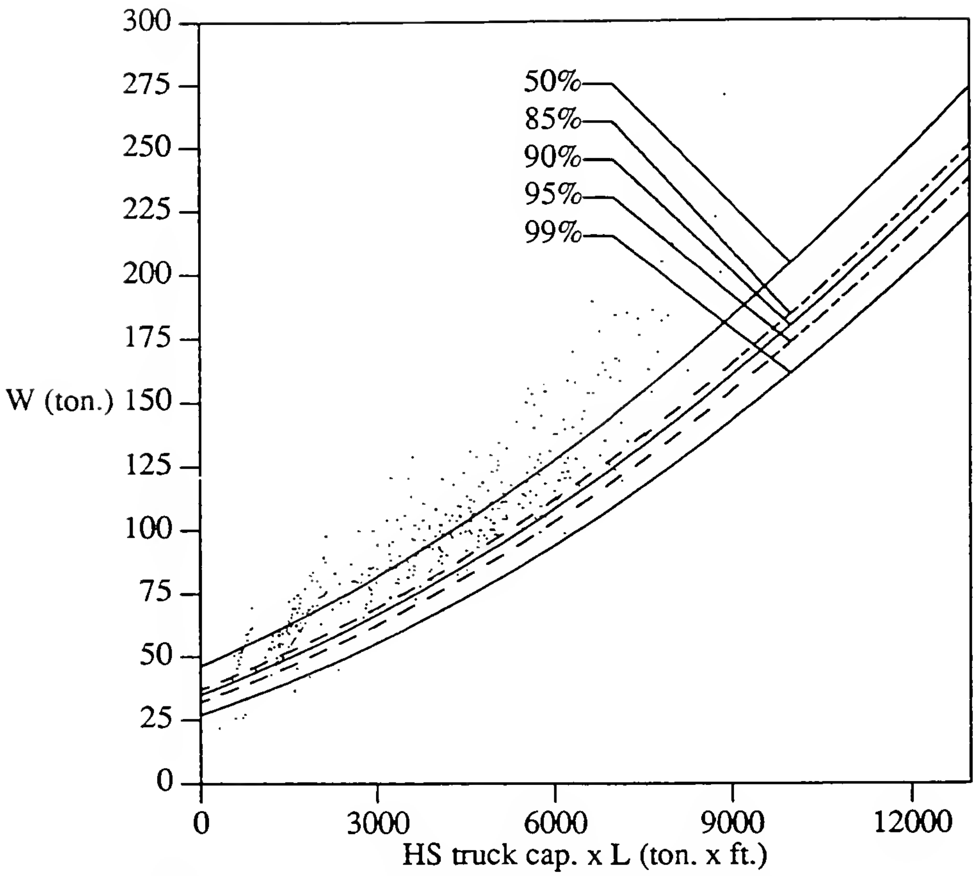


Figure 4.37 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for crcs bridges and for 10 ≤ L ≤ 120 ft.

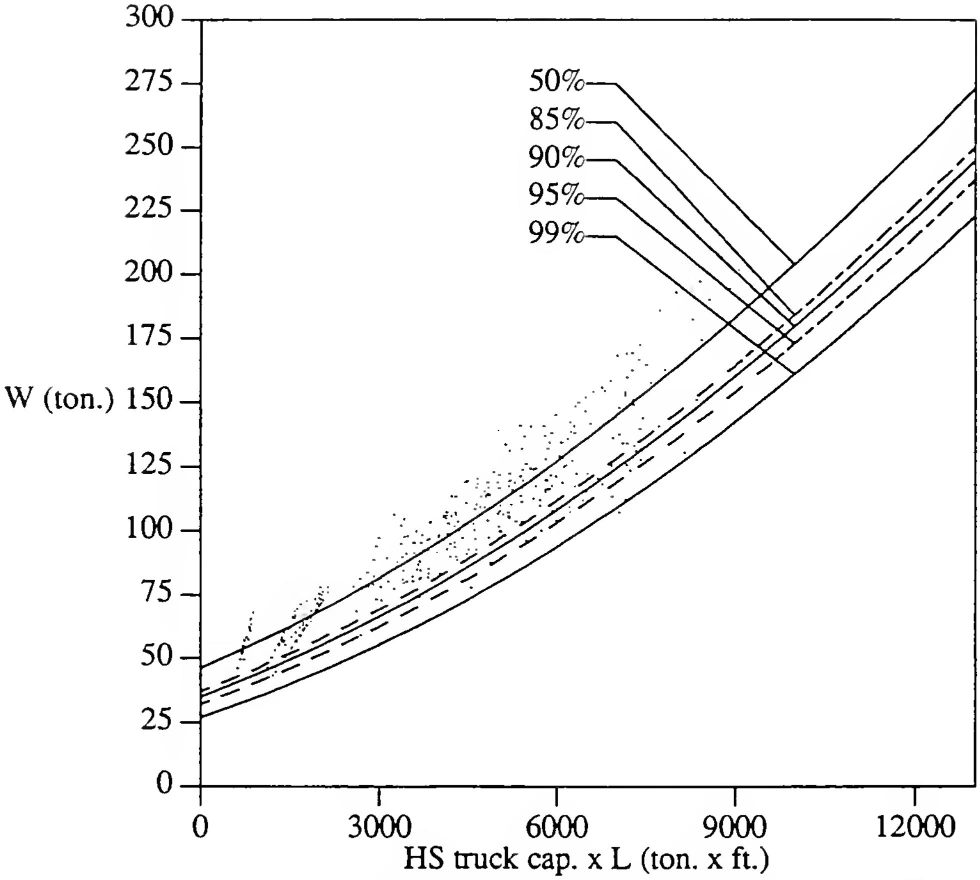


Figure 4.38 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for csb bridges and for 10 ≤ L ≤ 120 ft.

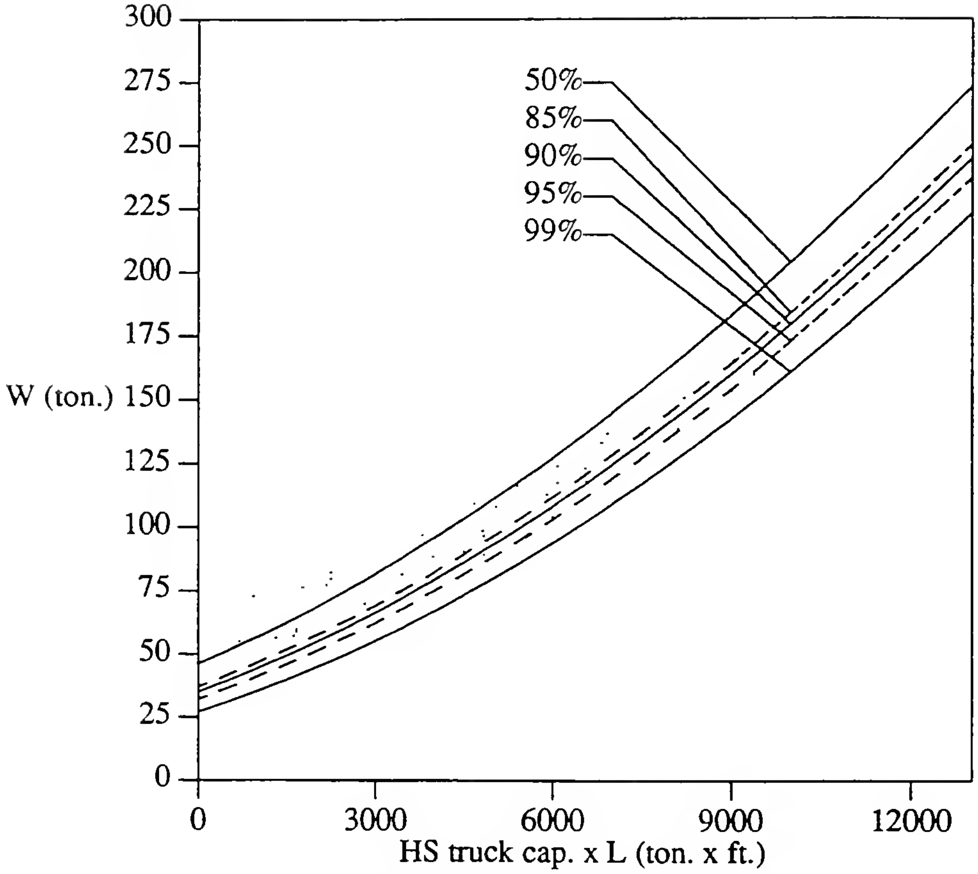


Figure 4.39 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for csg bridges and for $10 \leq L \leq 120$ ft.

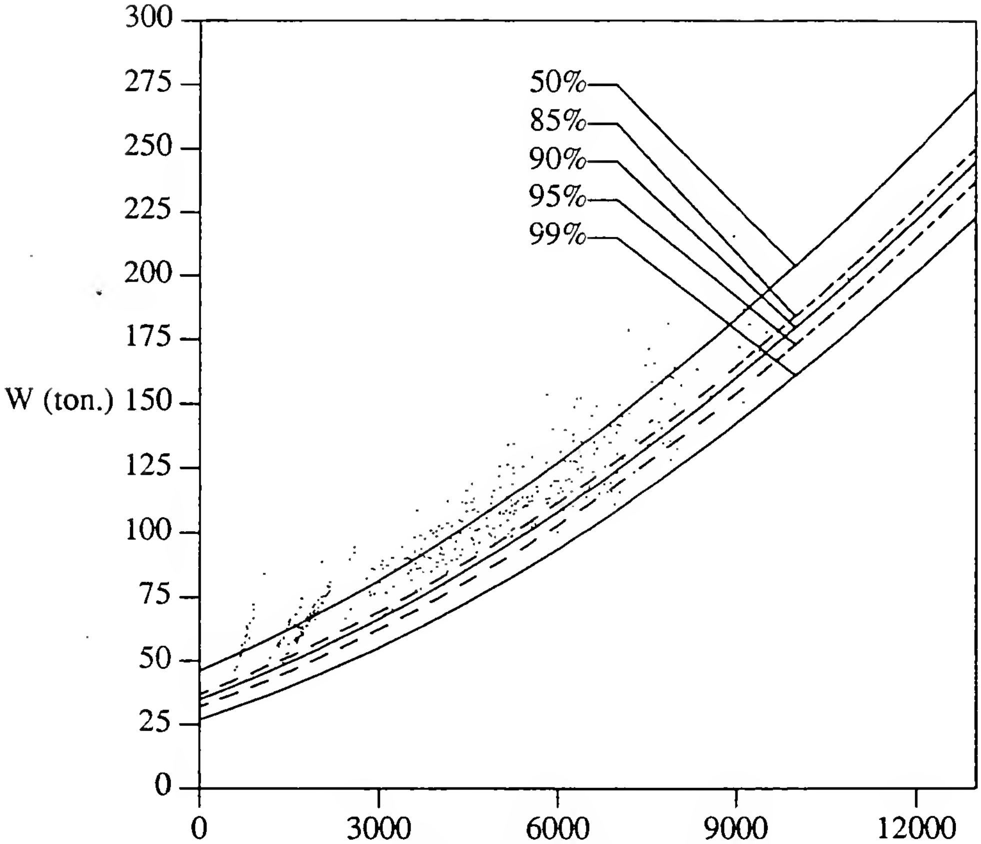


Figure 4.40 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for kcsb bridges and for $10 \leq L \leq 120$ ft.

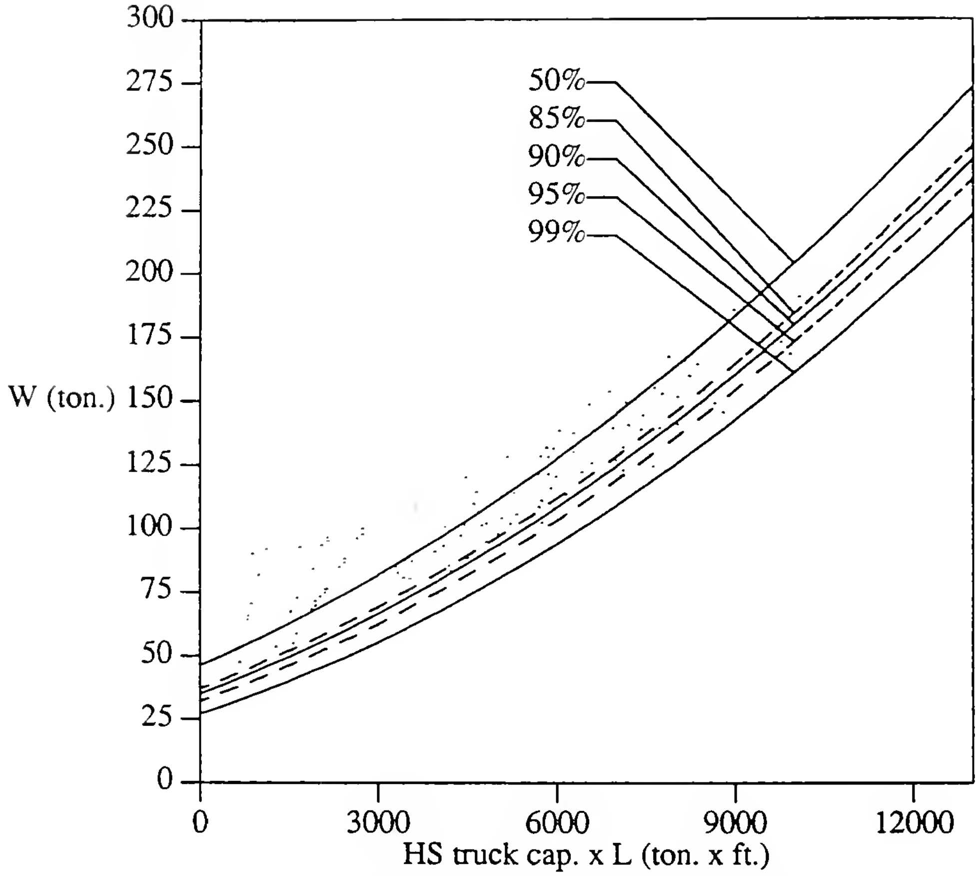


Figure 4.41 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for kcsg bridges and for $10 \leq L \leq 120$ ft.

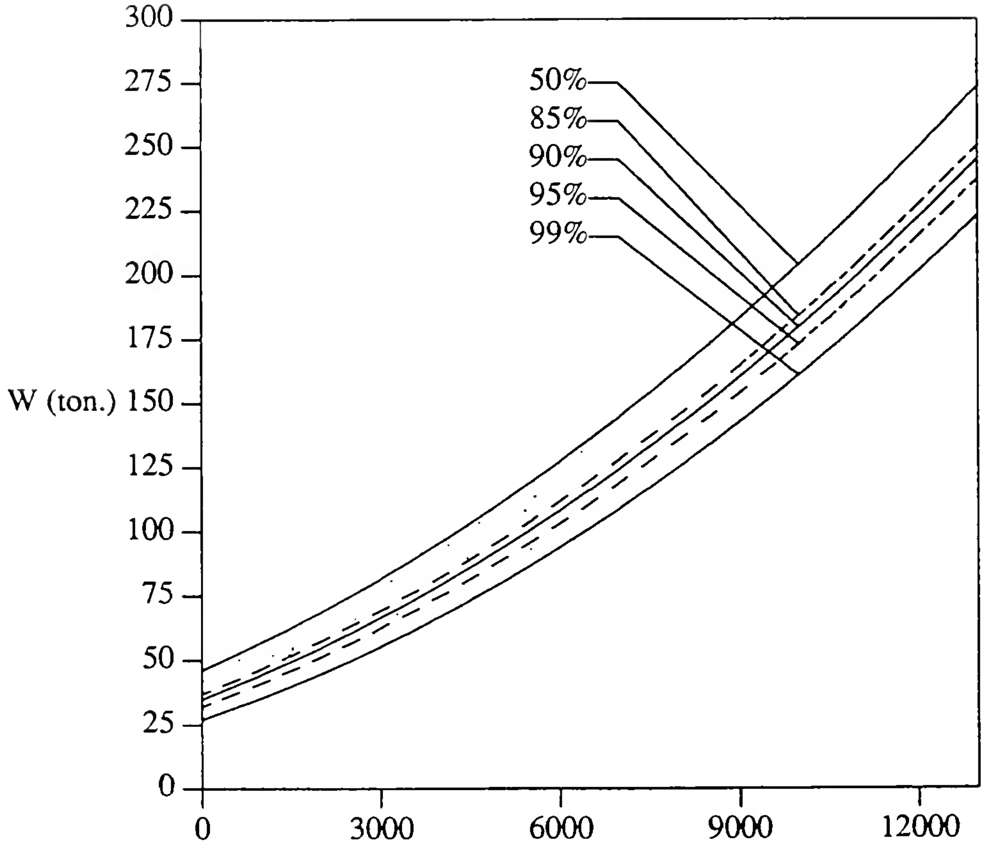


Figure 4.42 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for ksb bridges and for $10 \leq L \leq 120$ ft.

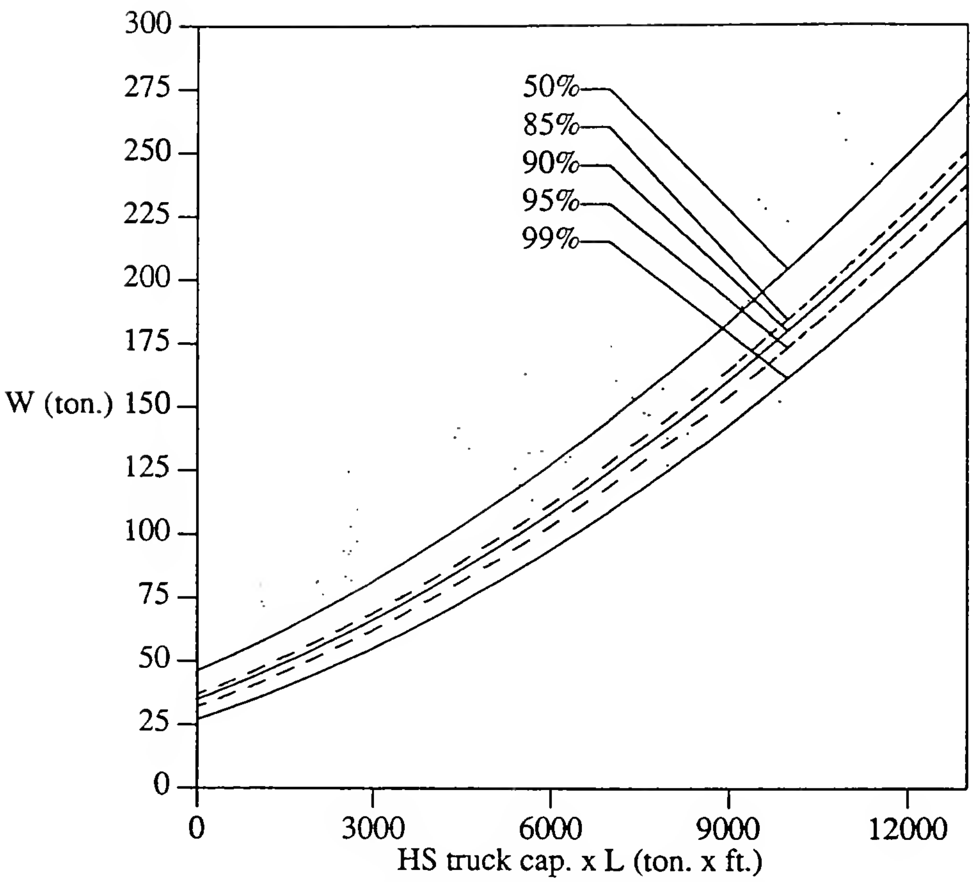


Figure 4.43 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for pcb bridges and for $10 \leq L \leq 120$ ft.

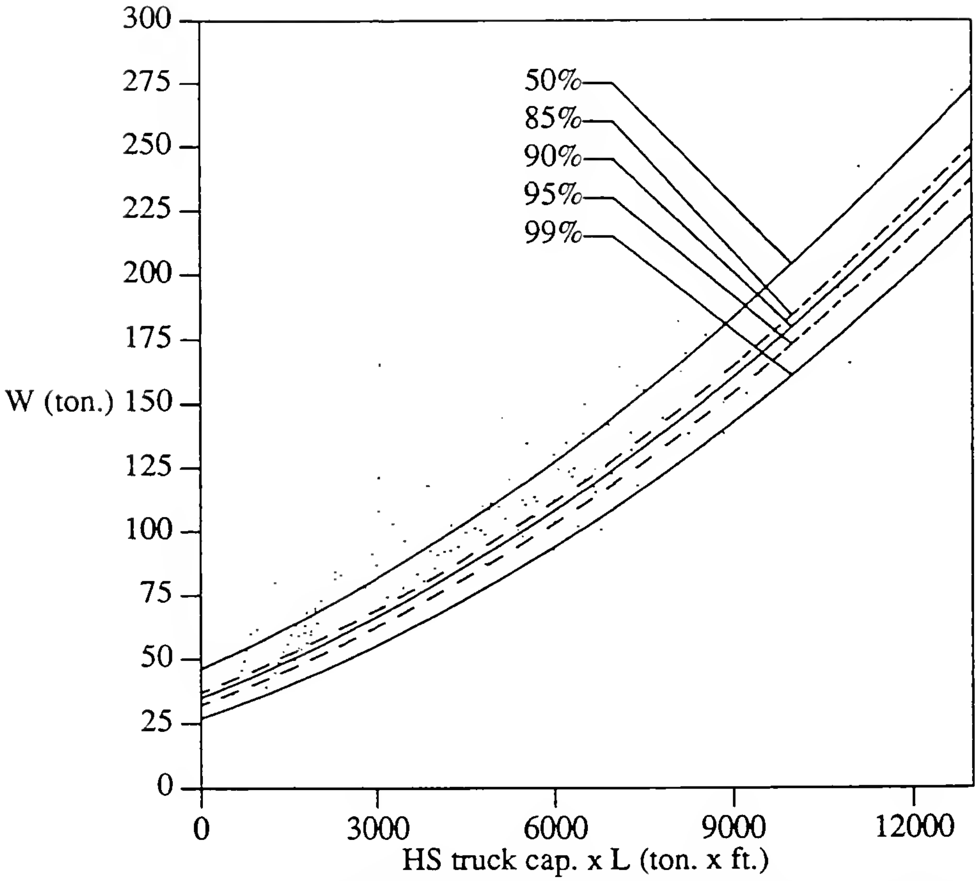


Figure 4.44 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for pcbb bridges and for $10 \leq L \leq 120$ ft.

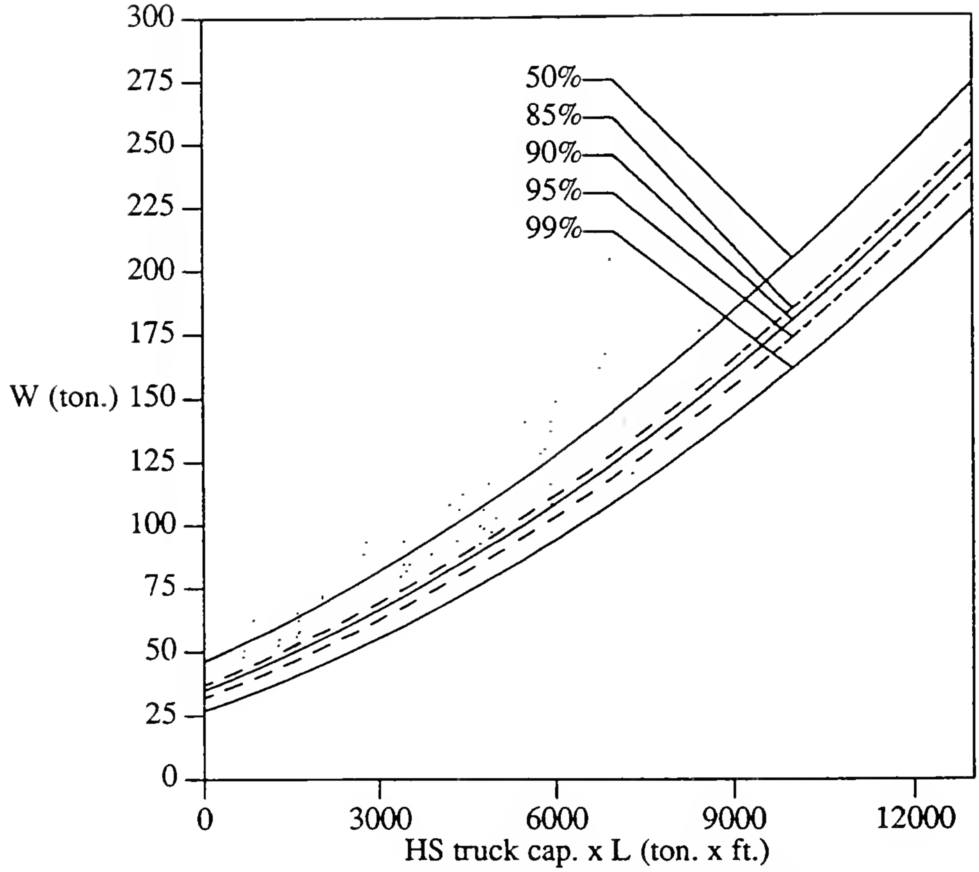


Figure 4.45 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for pcib bridges and for $10 \leq L \leq 120$ ft.

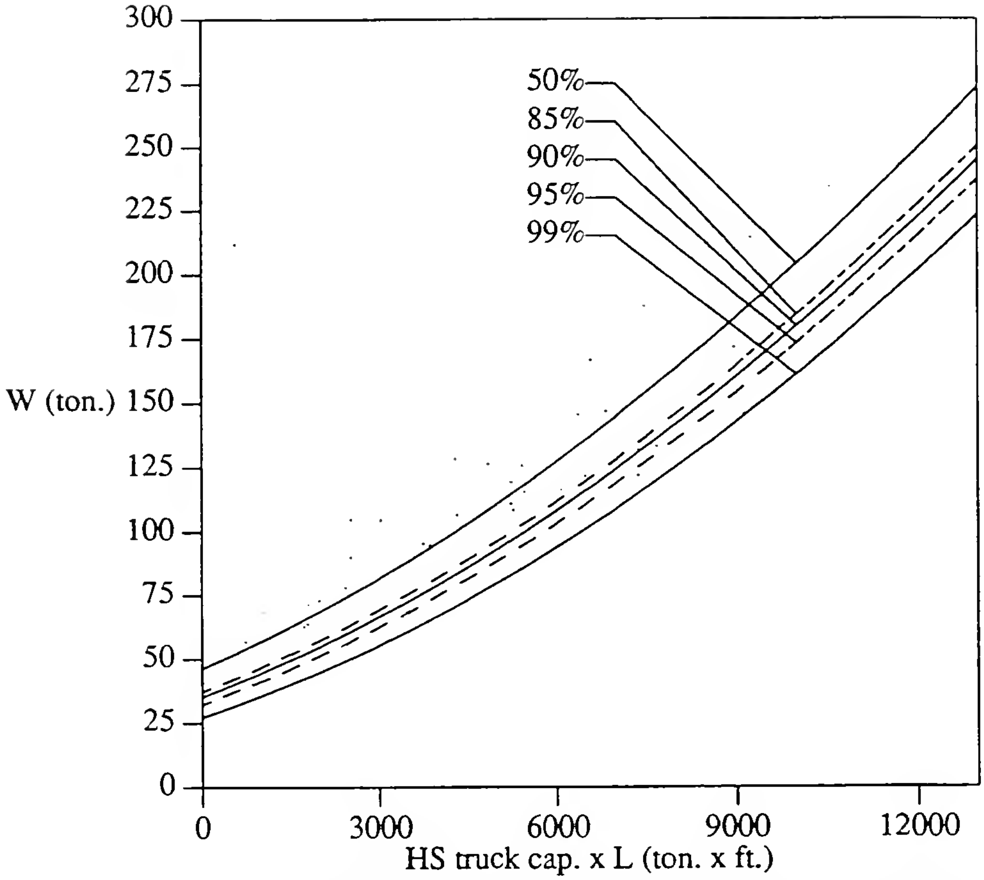


Figure 4.46 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for rca bridges and for $10 \leq L \leq 120$ ft.

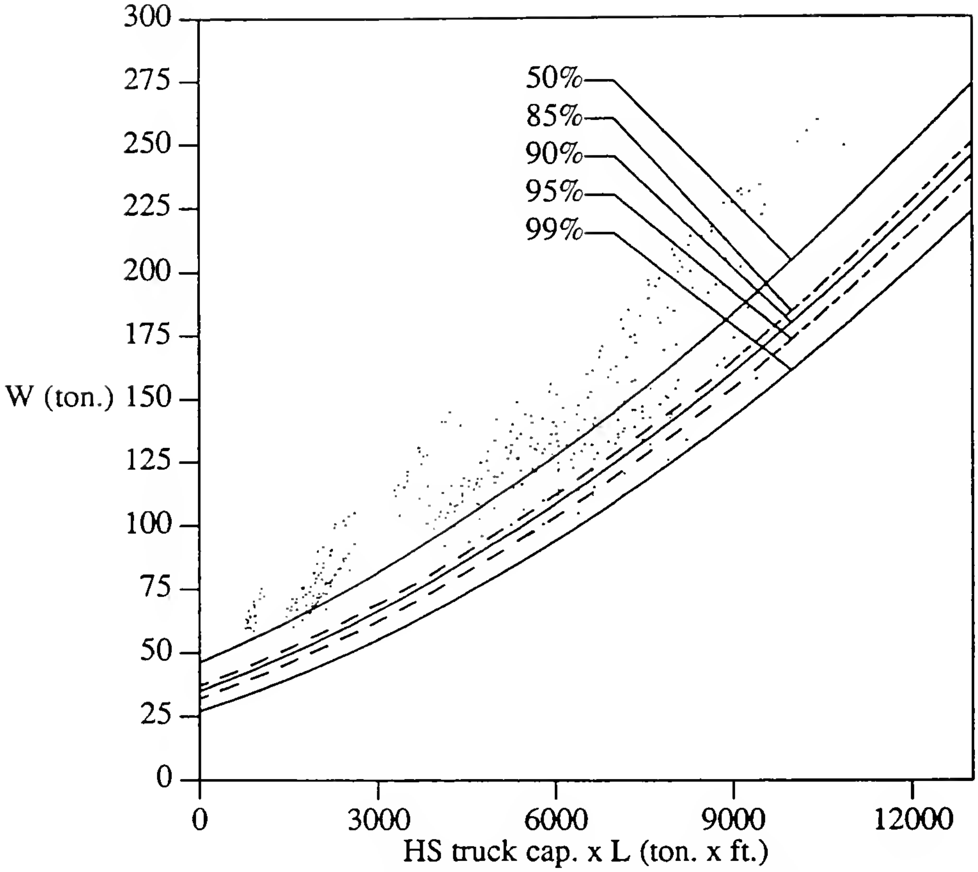


Figure 4.47 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for rcg bridges and for $10 \leq L \leq 120$ ft.

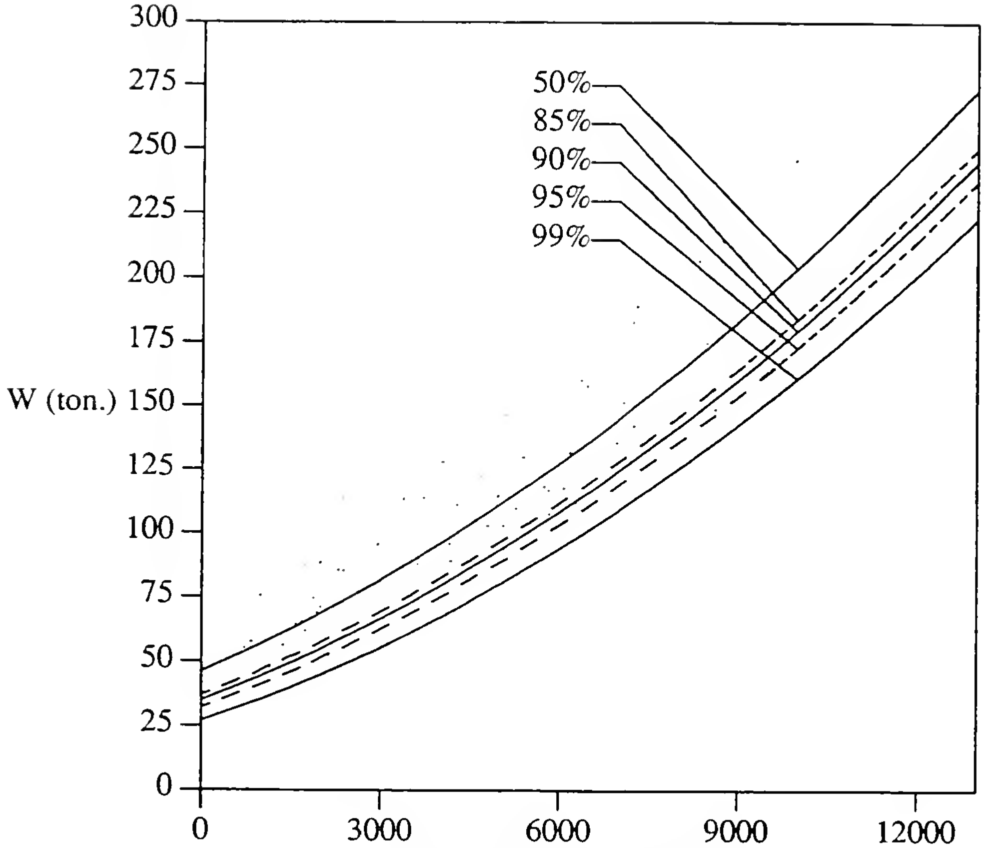


Figure 4.48 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for rcs bridges and for $10 \leq L \leq 120$ ft.

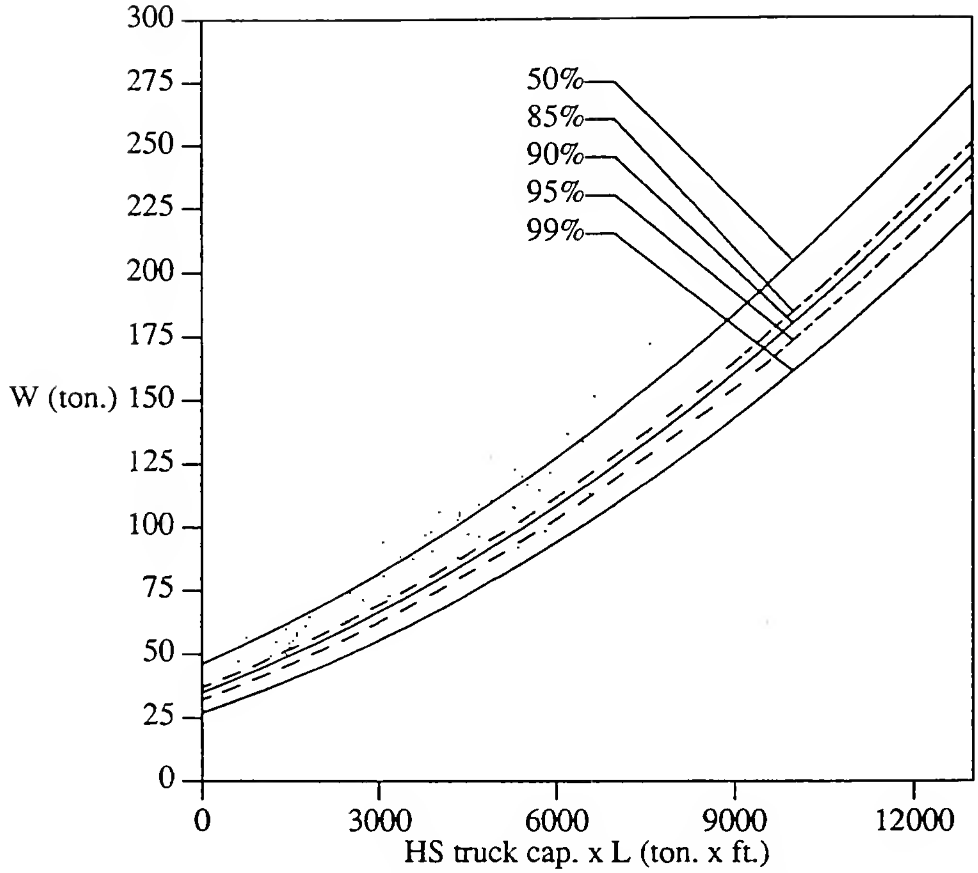


Figure 4.49 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for sb bridges and for $10 \leq L \leq 120$ ft.

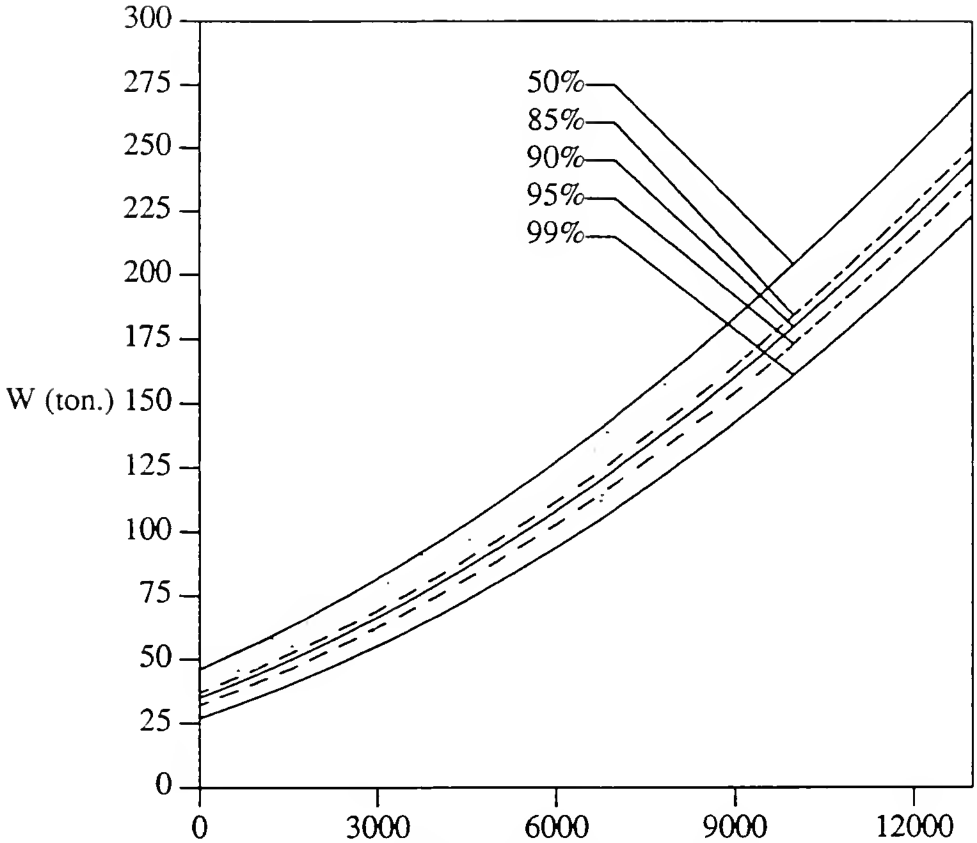


Figure 4.50 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for sg bridges and for $10 \leq L \leq 120$ ft.

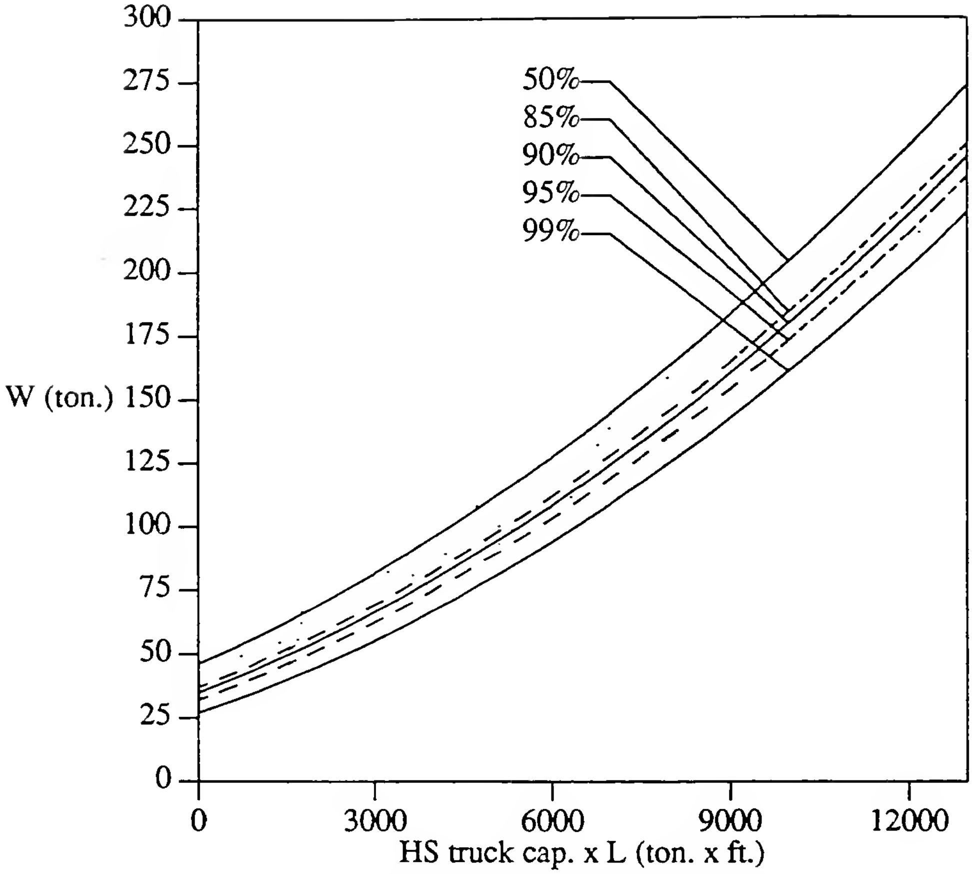


Figure 4.51 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for spt bridges and for $10 \leq L \leq 120$ ft.

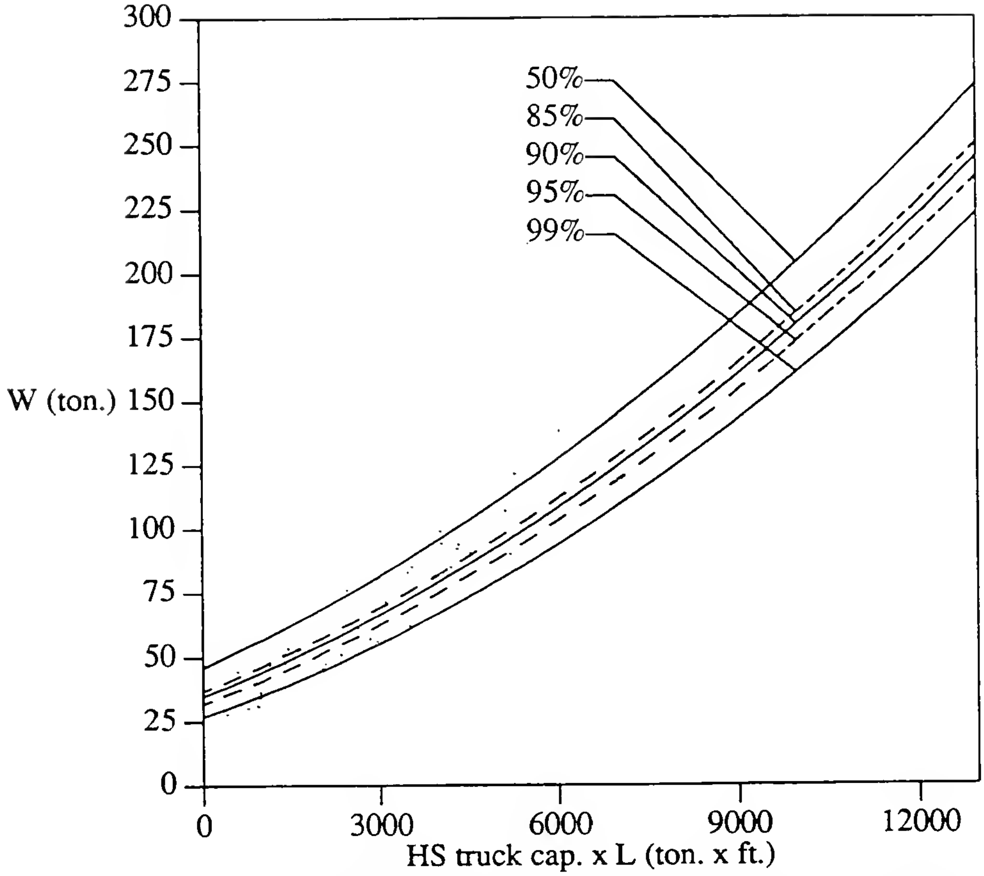


Figure 4.52 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for stt bridges and for $10 \leq L \leq 120$ ft.

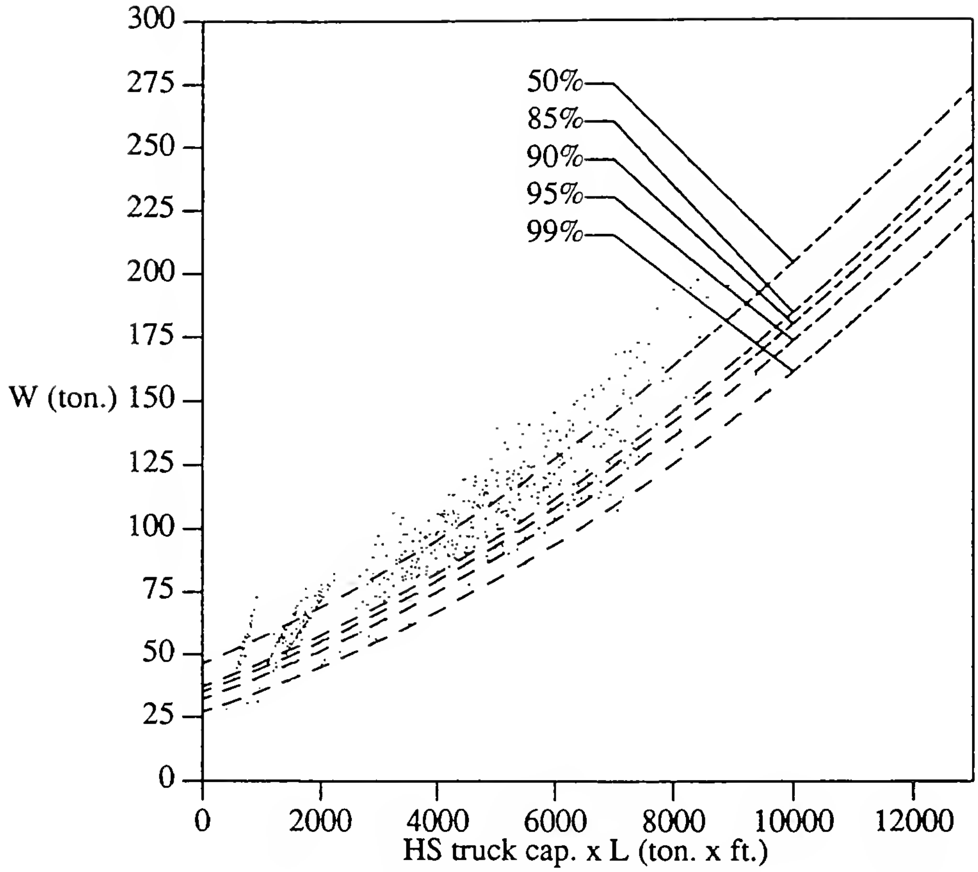


Figure 4.53 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for SS type bridges and for $10 \leq L \leq 120$ ft.

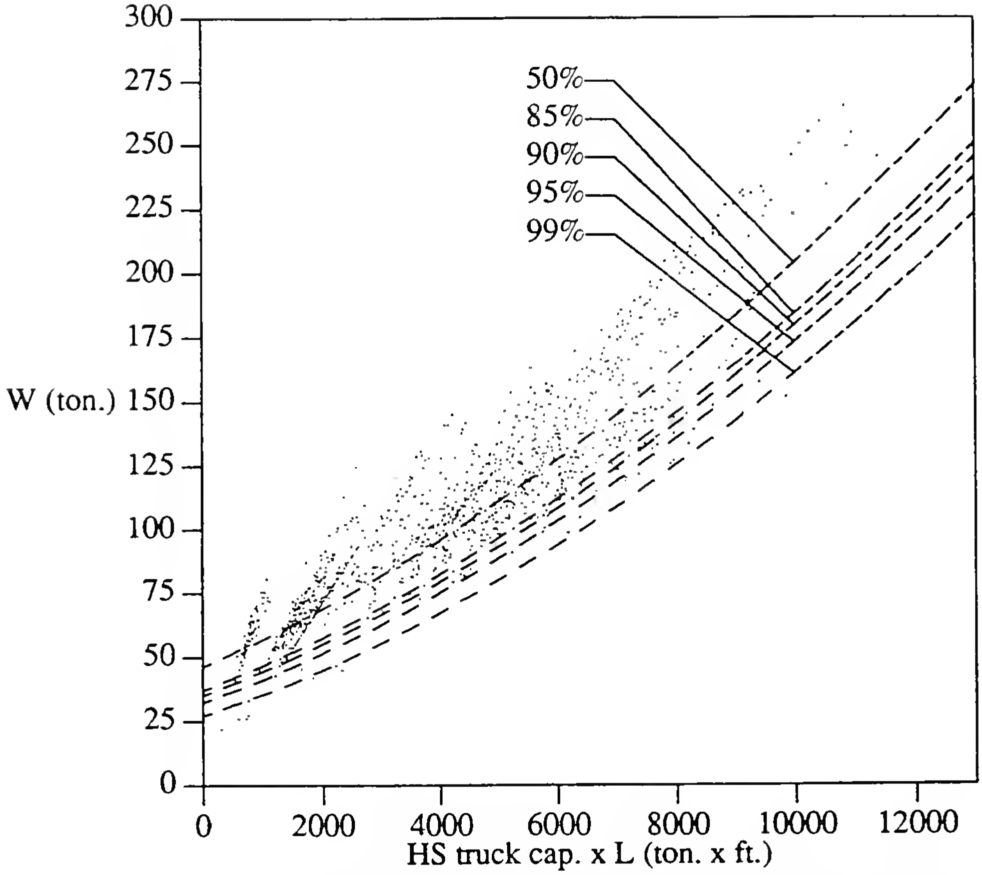


Figure 4.54 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for RC type bridges and for $10 \leq L \leq 120$ ft.

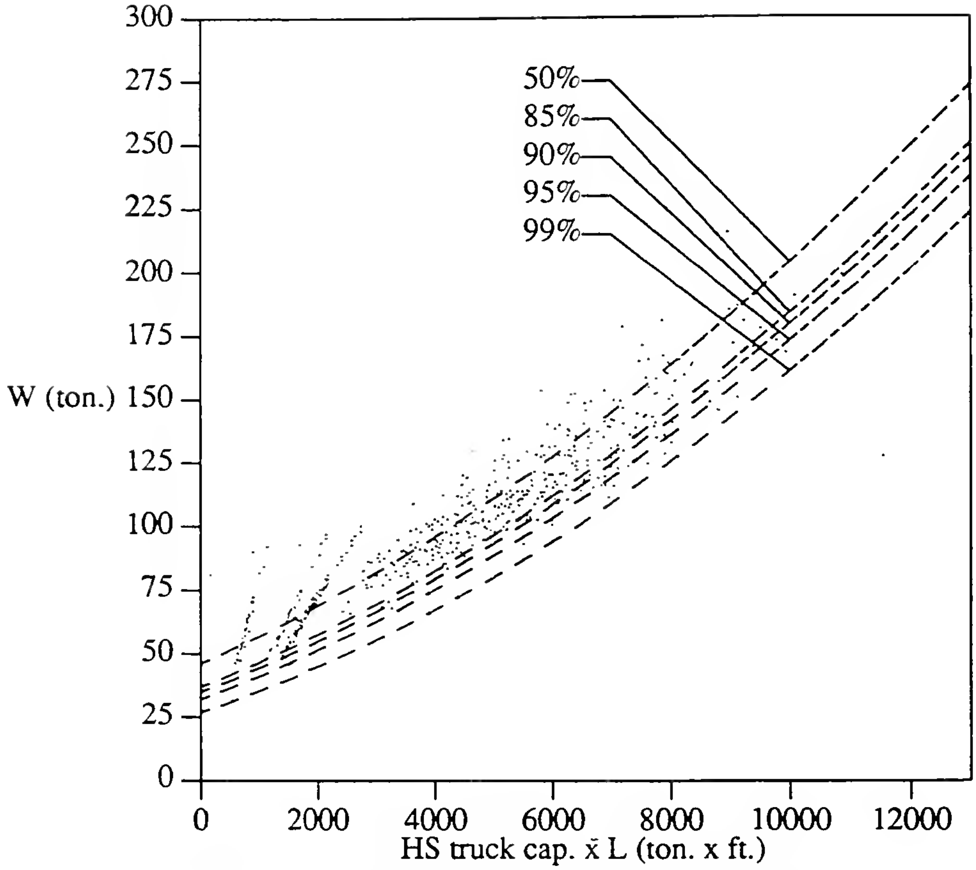


Figure 4.55 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for CSC type bridges and for $10 \leq L \leq 120$ ft.

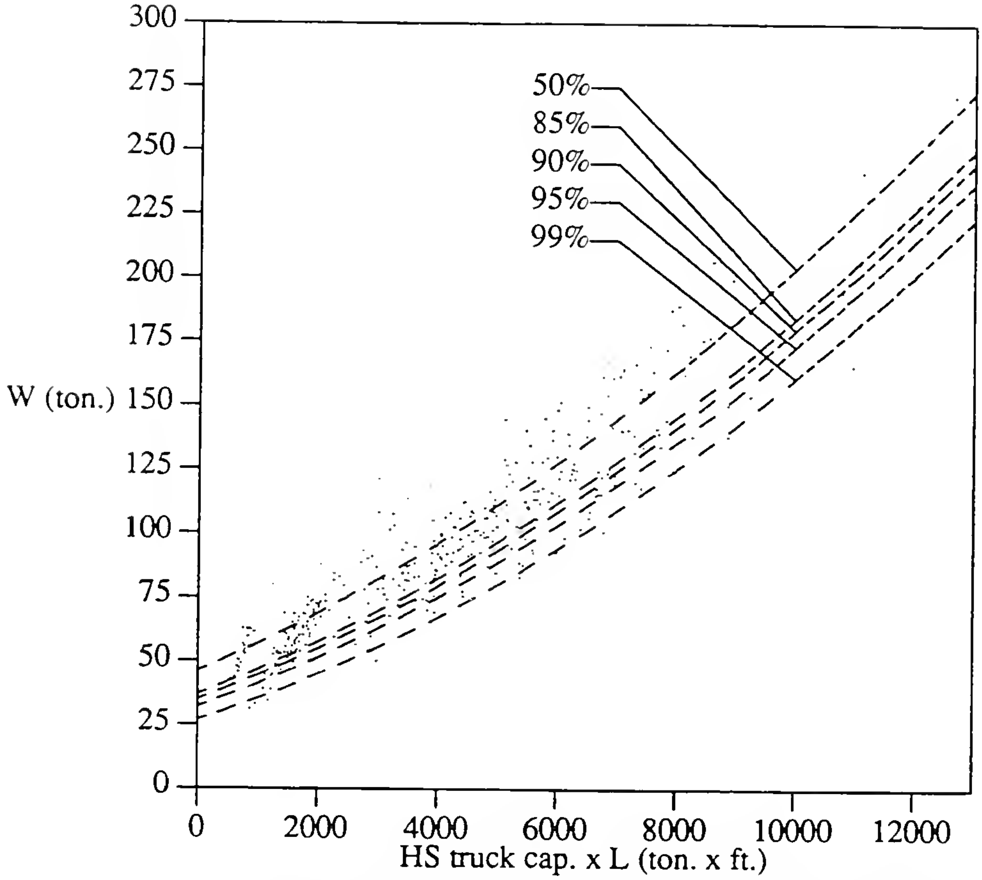


Figure 4.56 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for PSC & CPS type bridges and for $10 \leq L \leq 120$ ft.

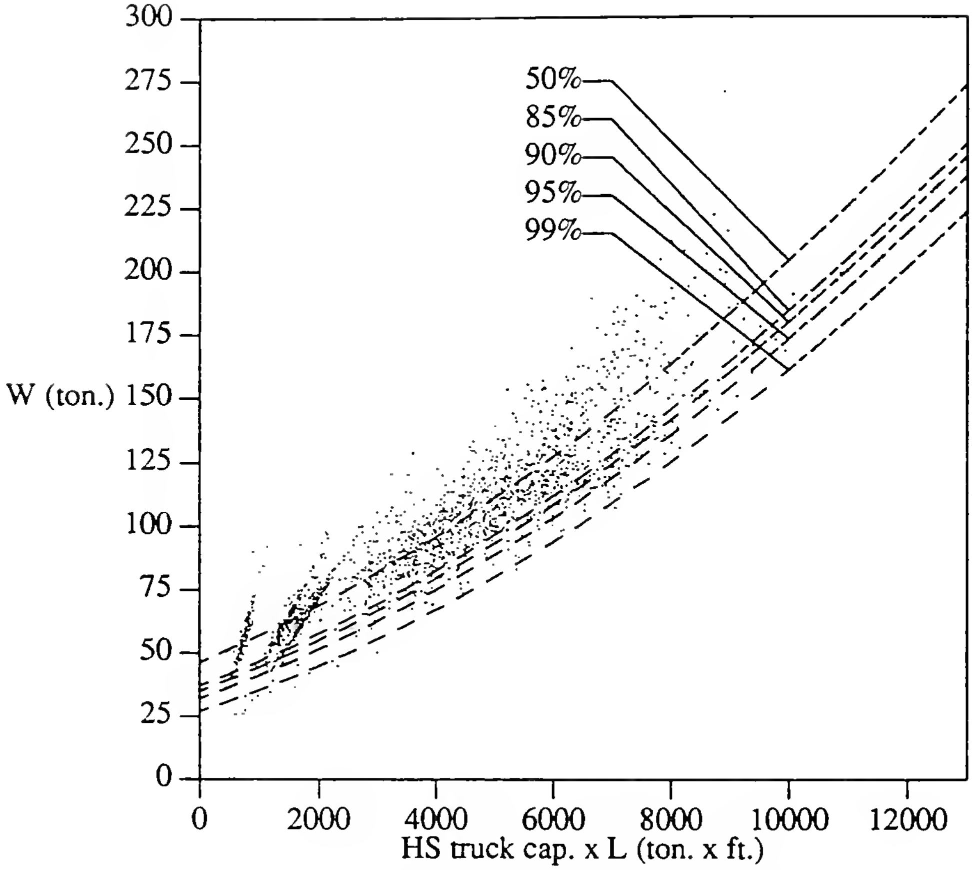


Figure 4.57 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for continuous bridges and for 10 ≤ L ≤ 120 ft.

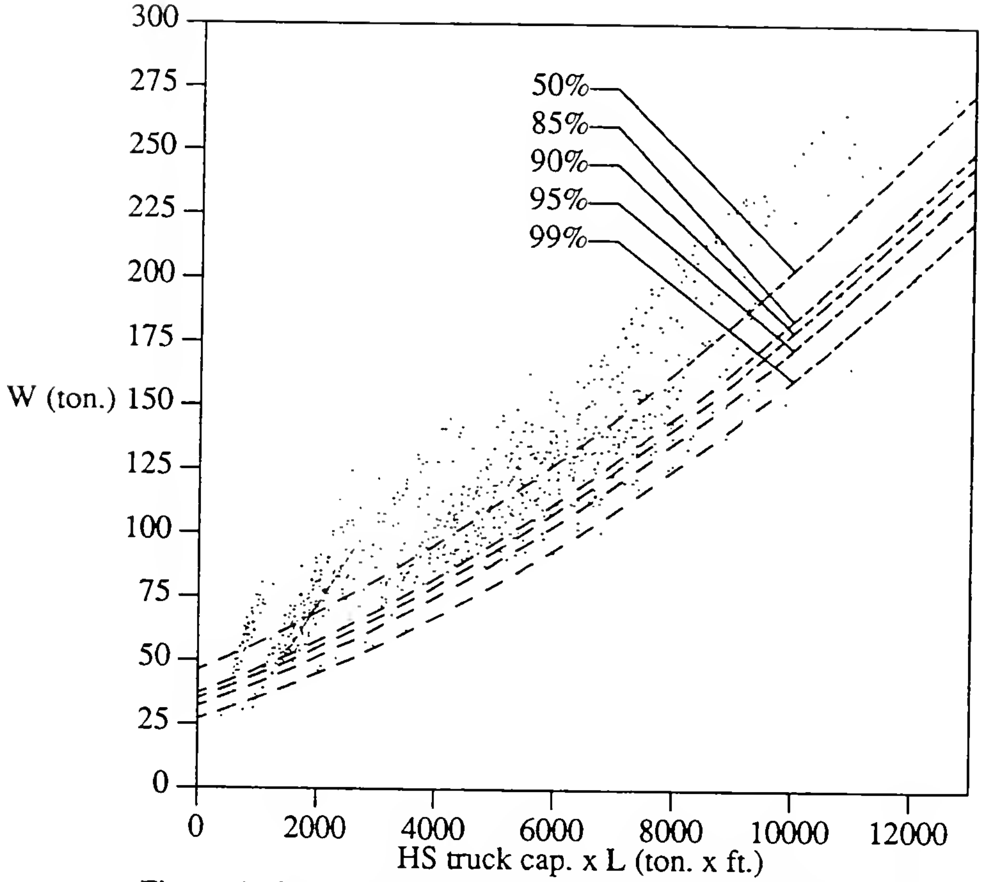


Figure 4.58 Allowable load, W, vs. the product of HS truck capacity and wheel base, L, for simple span bridges and for $10 \leq L \leq 120$ ft.

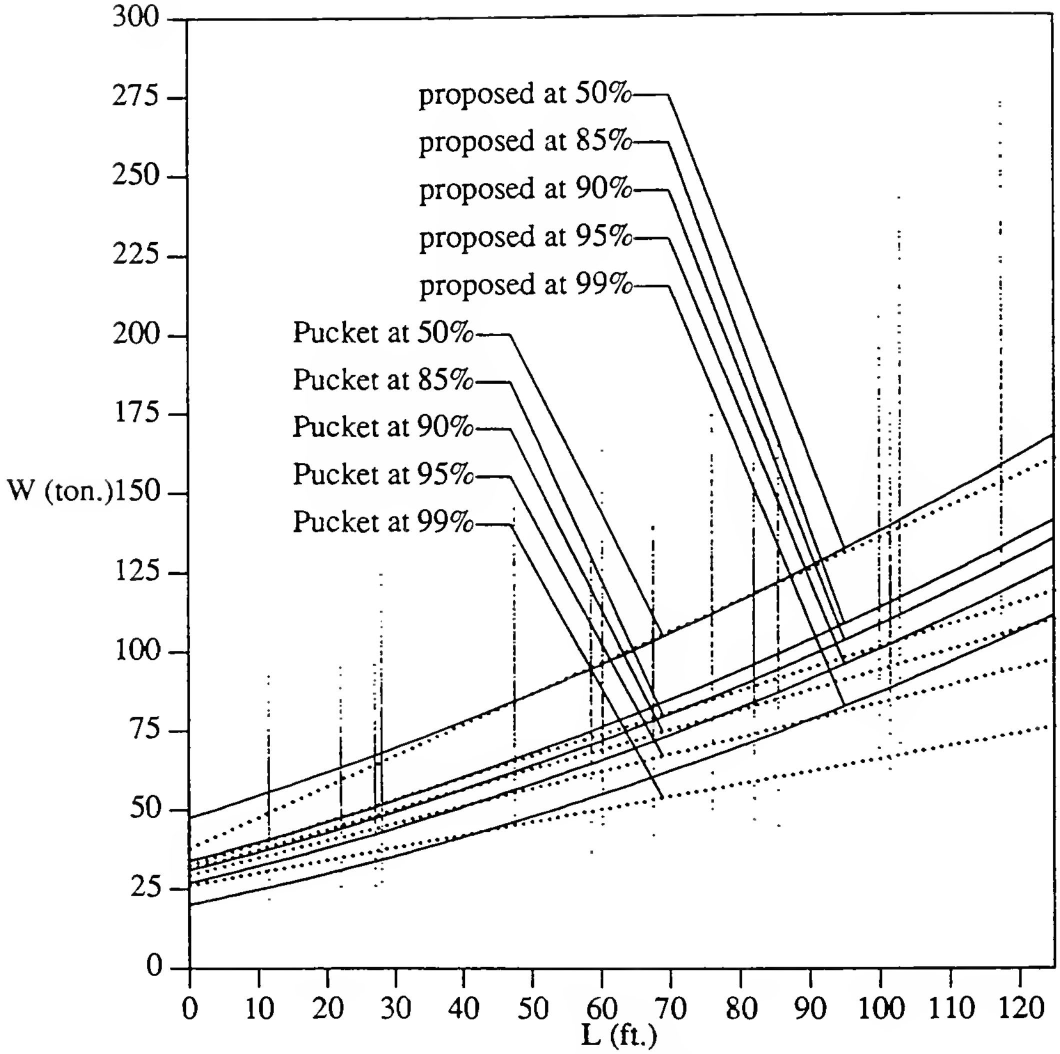


Figure 4.59 Allowable load, W, vs. wheel base, L, for 10 ≤ L ≤ 120 ft. superimposed on the proposed confidence limits and those by Pucket's study (1989) of Wyoming bridges, both studies involve bridge analysis at operating stress level

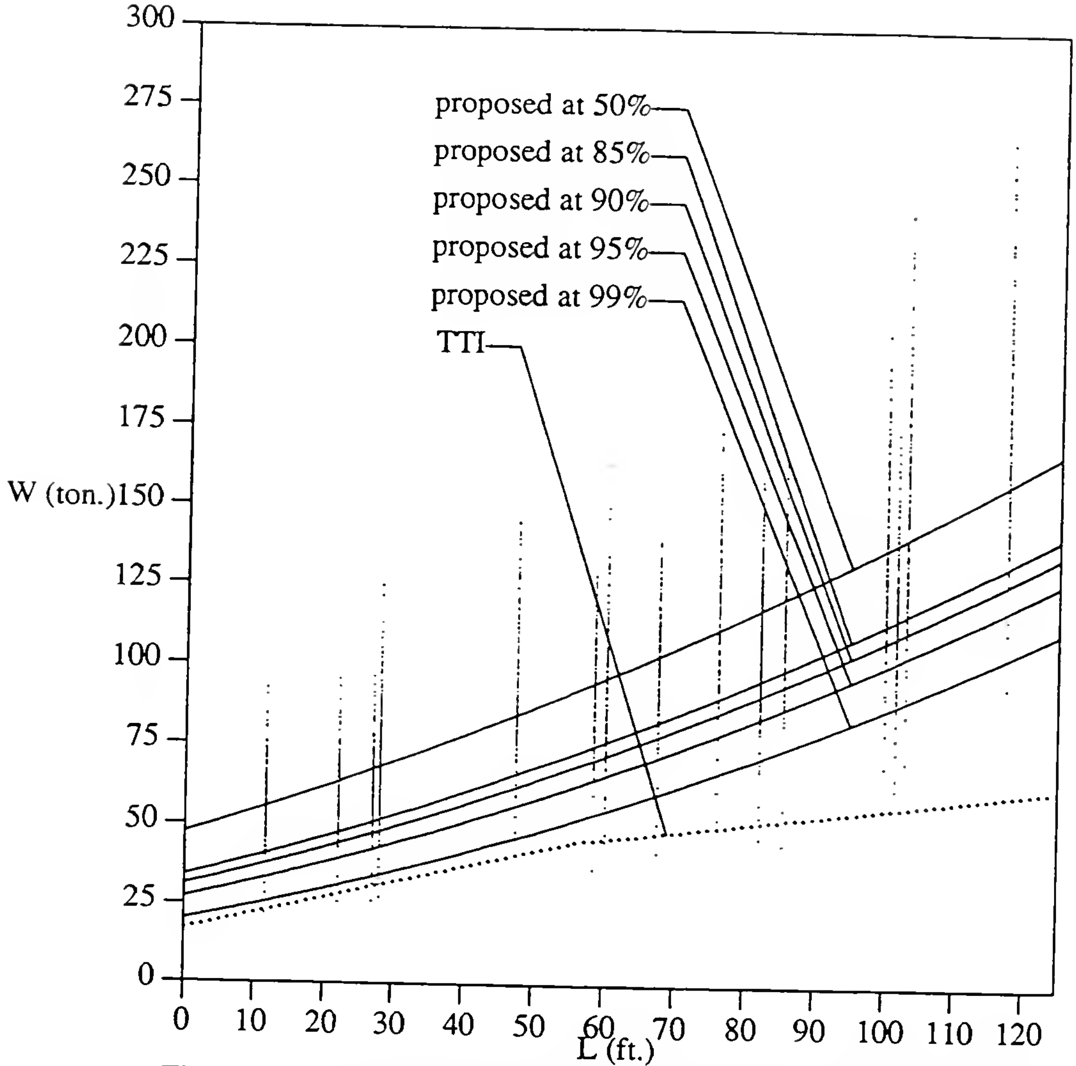


Figure 4.60 Allowable load, W, vs. wheel base, L, for $10 \leq L \leq 120$ ft. superimposed on the proposed confidence limits at operating stress level (i.e 36% overstress beyond design stress level) and that by Noel and James (1989) at only 5% overstress for HS20 designed bridges and 30% overstress for H15 designed bridges beyond design stress level

LIST OF REFERENCES

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APPENDIX

APPENDIX

Basic truck parameters used in this study

N - Number of axles.

L - Wheel base, distance between the front and the last axles.

N_{eq} - Number of equivalent axles, obtained by grouping the axles that are within 9 ft. length.

$\bar{x}$ - Distance of the resultant load from the front axle, calculated using the following formula.

$$\bar{x} = \frac{\sum w_i x_i}{\sum w_i}$$

where

x_i - distance between the front axle and the i^{th} axle.

w_i - load acting on i^{th} axle.

x_σ - Standard deviation of the vehicle load distribution along its length, calculated using the following formula.

$$x_\sigma = \sqrt{\frac{\sum w_i \left[x_i - \bar{x}\right]^2}{\sum w_i}}$$

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